ARCHITECTURE OF MACHINERY:

AN ESSAY

ON

PROPRIETY OF FORM AND PROPORTION,

Intended as a Guide to assist the Student in the Drawing and Designing of Machinery.

BY SAMUEL CLEGG, JUN., C. E.

Re-issue, for the Use of Students and Schoolmasters.

EIGHTY-FOUR WOOD-CUTS AND PLATES.

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ARCHITECTURE OF MACHINERY.

Architecture of Machinery:

AN ESSAY

ON

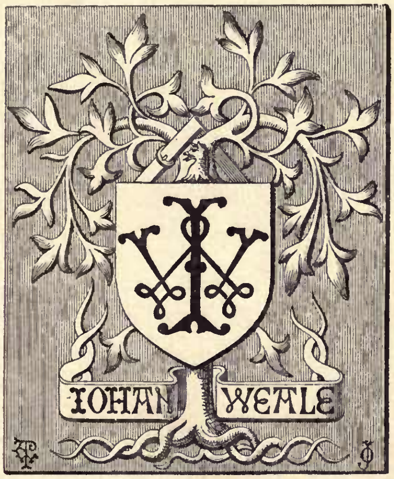
PROPRIETY OF FORM AND PROPORTION,

WITH A VIEW TO ASSIST AND IMPROVE DESIGN.

BY SAMUEL CLEGG, JUN., C. E.

AUTHOR OF A PRACTICAL TREATISE ON COAL GAS.

ADMONERE VOLUIMUS, NON MORDERE; PRODESSE, NON LÆDERE;
CONSULERE MORBIS HOMINUM, NON OFFICERE.



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TO

JOSEPH MILLER, ESQ.,

CIVIL ENGINEER,

THIS ESSAY

IS

RESPECTFULLY INSCRIBED.

LIST OF PLATES.

WITH SEVENTY-SIX WOOD ENGRAVINGS.

INTRODUCTION.

THE object of the following Essay is to inquire into the reasons of error, and to endeavour to point out certain rules for design, by attention to which the many irregularities in *construction* and *form* so constantly met with in machinery are to be avoided; and to explain the correct principles of "taste." That they are open to such an inquiry no one can doubt, and it is earnestly hoped that those who peruse this Essay will do so without partiality, or allowing any personal feeling to warp their sounder reason. That the opinions and remarks contained herein are open to criticism and animadversion, the Author cannot deny; but, at the same time, he cannot help expressing his conviction that the data upon which his reasonings are founded are correct, and might, if treated in a more able manner, be productive of the greatest benefit, not only to the manufacturing engineer, but to all those connected with machinery.

The daily increasing demand for machinery of every description,—the perfection at which workmanship or skill in manufacture has arrived,—and the facility with which every part is executed, render it of the utmost importance that the contrivances which constitute the *value* of those machines, and the workmanship which renders them capable of being made so truly beautiful, should be reduced to such rules of construction, that while they retain all their essential forms, they may produce pleasing effects upon the eye of an observer; and the best means to produce such an effect are now attempted to be set forth.

It must be remembered that the majority of those for whom machines are constructed cannot enter into the merits of their internal action or of their comparative performance; and therefore, not being willing to yield the right of opinion, judge from "outside show," as they would of a picture or statue, where the only aim is to charm the eye, or excite pleasureable sensations in the mind, by the representation of Nature in her more sublime effects. It is only on those who by their education are qualified to judge of intrinsic merit, that either Nature or Art can be said to produce correct impressions, since the mind is always influenced by custom. It may therefore be inferred, that in many instances the want of elegance in the contour of a machine is not only displeasing to the spectator, but disadvantageous to the manufacturer.

The numberless contortions that have crept into the "patterns" of some even of our best and most scientific engineers loudly demand that some attempt should be made to point out the *causes of the defects*, and means of obviating them. Meagre attempts at imitation of the antique should be carefully avoided when the adjacent parts are not capable of being made subservient or of corresponding form; but so seldom can this be done that the propriety of such an arrangement becomes the exception, not the rule. The leading features are often twisted and turned into distortions so unsightly, that it would appear as if the designer wished to show his contempt for regularity of forms "which, by the common consent of ages, are esteemed beautiful," by clothing his ingenuity and talent in ugliness. First impressions are always the most lasting, and it is evidently prudent that they should be pleasing.

Manufacturers are often bound down to work at low contract prices, and an excuse often occurs,—"a handsome thing cannot be made for such a sum;" but this is entirely a mistake. It does not cost one farthing more to construct an elegant figure, having beauty without an attempt at grandeur, than it does to create a deformity, or to make a machine in such a manner as to raise disgust by its pretensions at display. If

it be a casting, the first and principal expense is the "pattern;" and since this, once done, will serve for many machines, is it not advisable that great care should be taken in its original design? Surely the perpetuation of a good thing is preferable to the multiplication of ugliness. In wrought iron work this argument will not hold; but within certain limits it is always as cheap, nay, frequently cheaper, to work to a perfect as to an imperfect shape, more especially if it can be reduced, to turning in the lathe or fitting by templates. Nor is it only in the first formation that the cost is reduced; for if the work be set out by scientific rule, there is no necessity for change either in shape or disposition, and the same pattern or template will therefore serve as an universal model.

The beauty of a piece of mechanism will never depend upon the quantity of "bright work;" a *little*, to increase the effect of light and shade, and confined to the more prominent parts, is advisable in well "got up" work; but to overdo it is far worse than leaving it entirely black. A frame, a pedestal, a wrought iron rod or cross head, if out of proportion or possessing superfluous dimension, will look ill, whatever be its polish or material. Deformity decked out in finery is hideous, while that less obtrusive may be passed by.—"Pretend to nothing but what you are" will apply to man's handy work as well as to man himself, and to attempt to give beauty by polish, when the form is unsightly, must always be pretence.

Another very mistaken notion is that of *hiding* the essential parts of a machine by adding useless ornament. Mr. Pugin, in his work on 'The True Principles of Christian Architecture,' complains loudly, and on good grounds, that architects "*construct ornaments*" instead "*of ornamenting construction*," and the same holds good with engineers.

Every part and detail of a machine should have a distinct *meaning* with reference to the duty they have to perform; and if those parts are made in such a manner that they have strength in the proper place, stability without unnecessary weight, and simplicity of form without

meanness, they require no other ornament, because their own proportions will constitute their greatest.

If we had not the means of making our material in suitable forms without running to great expense, excrescences, distortions, and unmeaning incumbrances would be more excusable; but we have the means. Every facility which the ingenuity of man can devise in the shape of tools is given to the manufacturer; and let him argue as he will, he can bring forward no sound reason why the mechanical contrivances which have gone so far to raise us in the scale of nations should not be rendered as pleasing to the eye by their elegance, as they are useful by the perfection to which they have enabled us to bring our fabrics.

ARCHITECTURE OF MACHINERY.

The first consideration in the *design* for a steam engine (and to these machines the observations are confined) is the *quantity* of work each part has to perform: in other words, what weight it has to resist; in what direction the force or forces are applied with reference to its cross section and points of support; and the *times of impact* or velocity.

The calculations necessary to obtain these must not be confined to theory alone, neither should they be entirely deduced from the "rule of thumb" conclusions, which practice without the guidance of mathematical knowledge would arrive, or rather, jump at; because, by the first, the parts would be liable to insecurity from the sudden jerks or changes in velocity always occurring in machinery, but which cannot be expressed in formulæ;—by the second, it is more than probable that weight would be added in unnecessary places from the determination to avoid fracture, and the want of knowledge respecting the true figure.

The figures best adapted for resistance in any known direction have been fully demonstrated, and the student is referred to the works of Tredgold or Barlow for information upon these heads,—books well adapted to their purpose, and possessing the rare qualities of theory and practice combined to a valuable extent.

As general rules, to which there are but few exceptions, the following may be given:

For *transverse strains* the figure must have a parabolic section opposed

to the force, or "some simple figure to include the parabolic form." Fig. 1.

The vertex must be at the point where the force is applied. Fig. 2.

Where the strain is first in one direction and then in an opposite one, the curve must be on both sides. Fig. 3.

Against *direct strain* a *straight line* must be opposed; and stability and non-vibration insured by the intersection of planes, so that the section will be a cross or a portion of one, or some form that will include that figure. Fig. 4.

And for *tortion* the section must be a circle.

Fig. 1.

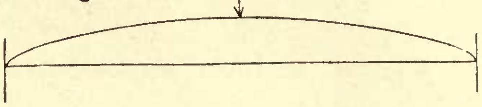


Fig. 2.

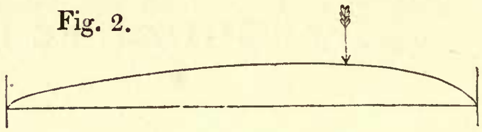


Fig. 3.

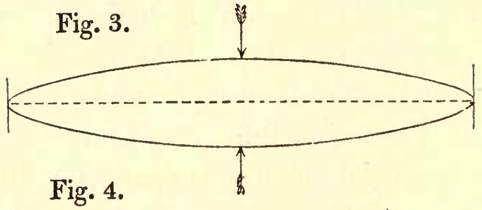
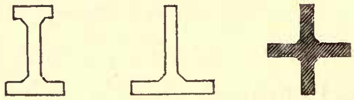


Fig. 4.



All parts of the machine, in whatever situation and under whatever circumstances they may be placed, may be shaped in these simple figures; and if the calculations for their dimensions are made from correct data, the form of greatest beauty is arrived at directly. The most conspicuous parts should have *boldness of outline*, and as much relief as possible, consistent with the purposes to which they are applied.

A bold outline being gained, it will remain to *relieve* the separate parts, and it may, perhaps, be said that *relief* should be the term used to express ornament in machinery; but if it be considered essential to use *ornament*, the stationary portions alone should be thus *embellished.*

For the purposes of relief, the eight regular architectural mouldings may be used, which are, the *Fillet*, fig. 5, introduced principally to separate the members, or relieve a profile: in the latter case, as in fig. 6,

the under side should be joined to the face of the die or other surface by a hollow: its projection is equal to its height.[1]

Fig. 5.

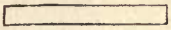


Fig. 6.

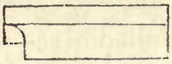


Fig. 7.

Fig. 8.

Fig. 9.

Fig. 10.

Fig. 11.

Fig. 12.

The *Scotia*, fig. 7, is also used to separate members, should always be placed below the eye of an observer, and never upon a cornice or moulding: its projection is equal to one-third its height.

The *Ovolo*, fig. 8, on the contrary, should never be employed but with upper mouldings: its projection is equal to its height. In this example it is composed of the quadrant of a circle; in the Grecian character it may be the quadrant of an ellipsis.

The *Torus*, fig. 9, forms a portion of base mouldings, is employed on circular figures, and is usually separated from other members by fillets: it projects half its diameter from the fillets.

The *Talon* or *Ogee*, fig. 10, is used in upper or supporting mouldings: its projection is equal to its height.

The *Cyma Recta*, fig. 11, according to some, should only be used in "crowning members;" though in many specimens of the antique it is found in base mouldings: its projection is equal to its height.

The *Cavetto*, fig. 12, "must not be seen in circular bases or capitals;" that is to say, it is only valuable where angles occur: its projection is equal to half its height.

There are various manners of describing the contour or outline of mouldings; the simplest, however, and the best, is to form them of quadrants of circles, as in the annexed designs, by which means the

[1] When it has a less projection, it is sometimes called a 'Plat-band.'

different depressions and swellings will be more strongly marked, the transitions be made without any angle, and the projections be agreeable to the doctrine of Vitruvius, and the practice of the ancients.

In a late work on architecture there is the following note, which agrees with some observations before made. "All sense in the application of appropriate forms in mouldings seems now extinct, and Palladio set at defiance. He who can in the present day produce the newest and most extraordinary moulding in profiling an order is the greatest genius."

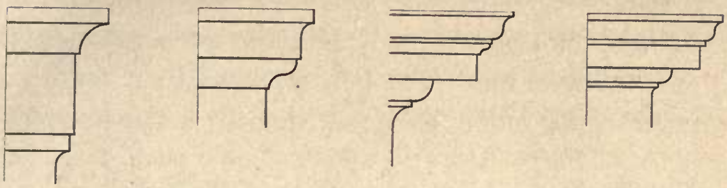
It is not advisable to give the same projection for a cornice, or other system of mouldings in cast iron, as in stone, for many reasons, but there is no cause for deformity and burlesque. If the general style of the engine will not admit of *architectural* contour, lay it aside entirely, and be content with relieving the *mechanical* contour.

In Plate I. will be found some examples of mouldings that have been executed in metal; those which are to be avoided were taken from similar situations to those where the upper combinations were found, and are fairly contrasted: the eye will be the best judge of their respective merits.

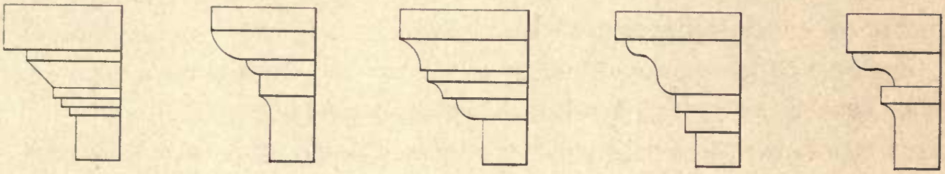
The three pedestals were also taken from similar works, and were all of nearly the same height. No. 3 is meagre, and totally devoid of that appearance of strength which a foundation ought to exhibit, and which is possessed by the other two.

Pedestals cannot be dwelt upon without notice being taken of the very general error of breaking the lines of the base and cornice used to relieve the tanks of "portable engines," in order to give a projection to each of the six columns, and to form a separate pedestal to each; they have the appearance of figures upon stilts, requiring effort to retain themselves in a vertical position; but when in addition to this they are elaborately panelled or stuck over with laurel wreaths, they become very miserable failures in the attempt at something elegant. A cornice on a pedestal or tank is necessary for stiffness; a base is also useful to convey an idea of stability.

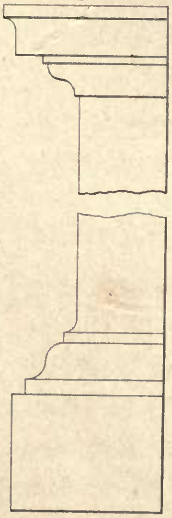
Regular Mouldings, executed in Cast Iron.



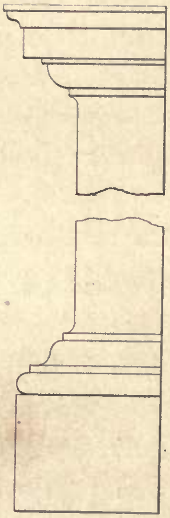
Mouldings to be avoided.



Regular Pedestals, executed in Cast Iron.

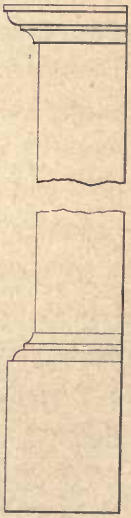


TUSCAN.



DORIC.

N.º 3.



John Weale, Architectural Library, 59, High Holborn.

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Cast iron being a material of so much greater strength than stone, such high relief is not essential; but this must not lead to meanness of outline.

From the best works that have been executed, the proportions may be taken as follow: divide the pedestal into ten parts, fig. 13; give one part

Fig. 13.

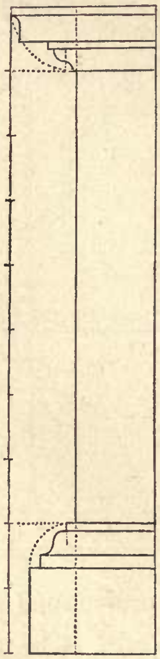
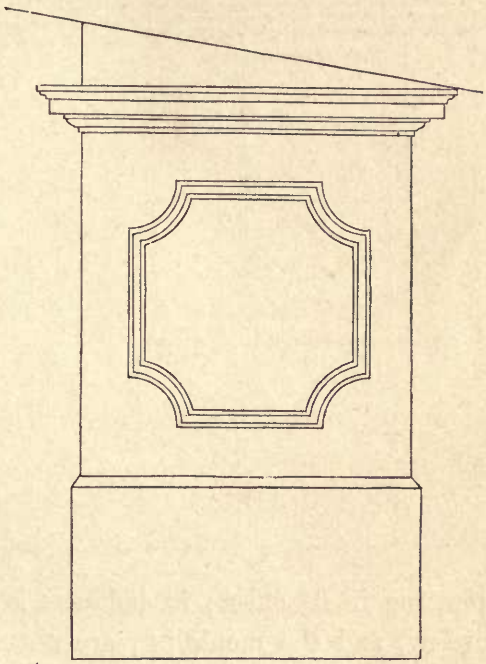


Fig. 14.



to the cornice, and two to the base; let the projection of the cornice be equal to its height, and that of the base to one-third thereof: or divide the base into three parts; give one-third to the mouldings, make the projections of the upper members equal to their height, and the plinth will drop from beyond the lower fillet. The pedestal may be divided into twelve parts, without being poor; but the first proportion is considered the best.

Fig. 14 is from the condenser front of a large marine engine, and is in tolerable proportion; the base mouldings are dispensed with, because the

beam will hide the lower portion: the panel is introduced as a relief against the large flat surface of the die. Fig. 15 is both less correct and

Fig. 15.

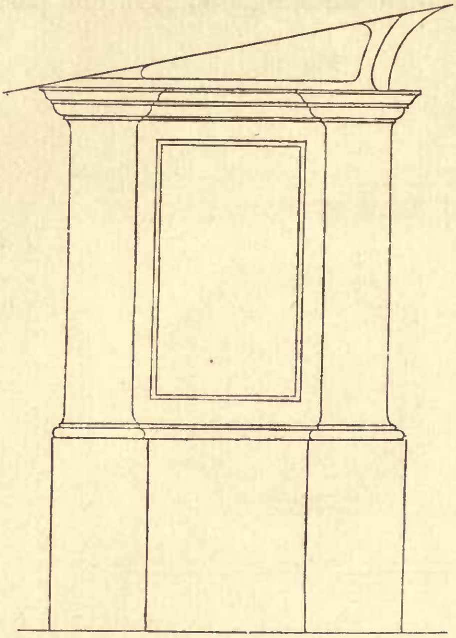
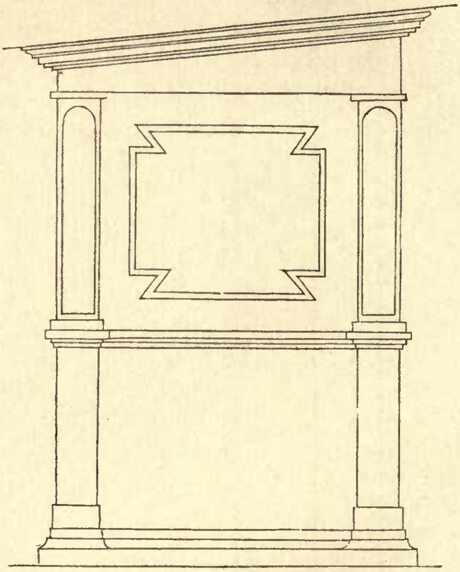


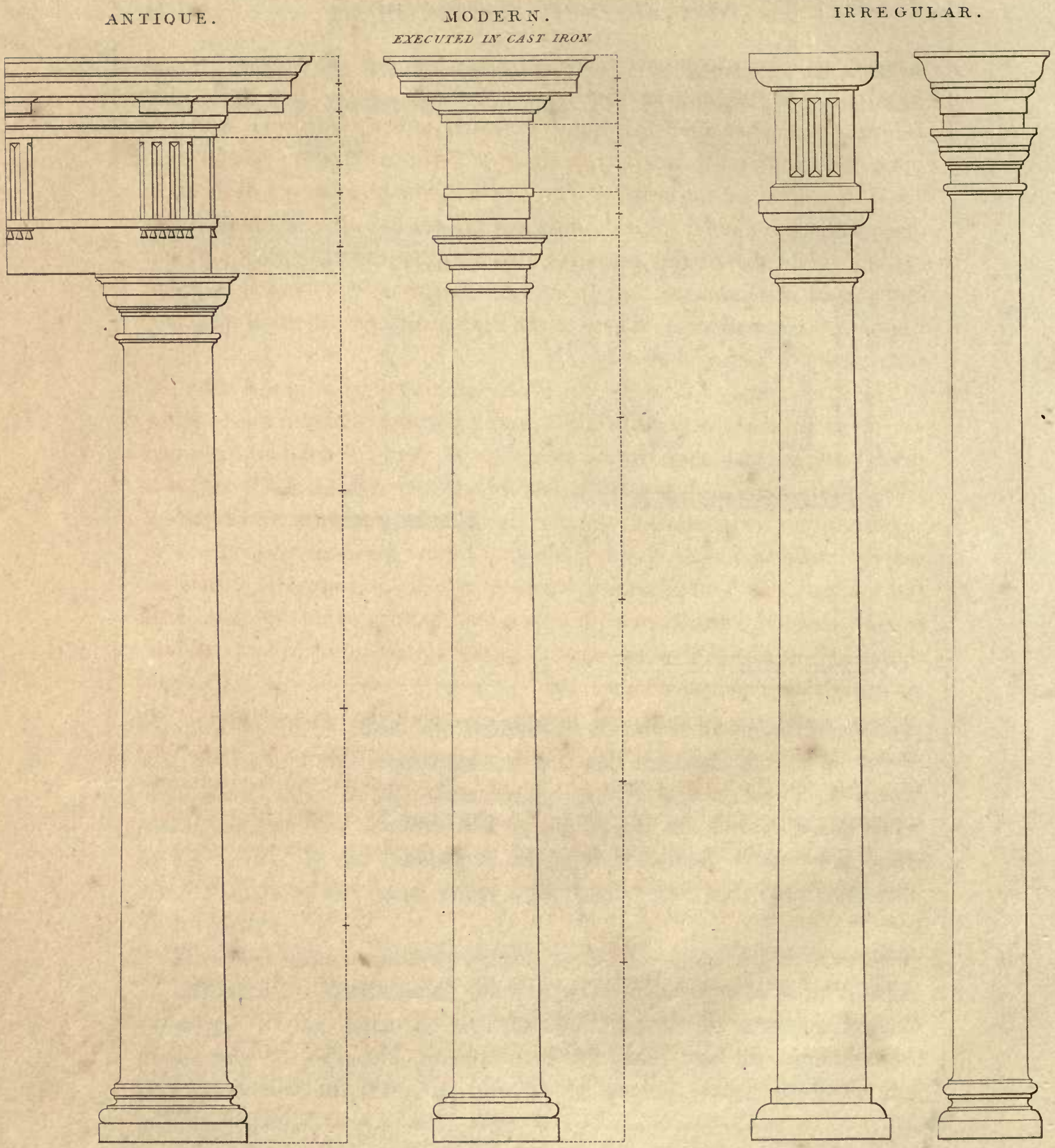
Fig. 16.



less pleasing in its effect; its boldness is destroyed by projections which are useless, and the mouldings are not well relieved; still it is not so unpleasantly mean as that shown in fig. 16, which is cut up by ill-shaped panels and pilasters, and distorted by the line of the cornice being made to follow that of the framing to which it is bolted. The lower parts being hidden by the beam, much work might have been dispensed with in the pattern.

When any superincumbent weight has to be supported, it is as usual to introduce an architectural column in machinery as it is in a stone building. In the latter the strictest and most severe attention is paid to the relative form and proportion of the parts, that the same feature may be carried out from the base to the coping stone; whilst in the

CONTRASTED DORIC COLUMNS.



John Weale, Architectural Library, 59, High Holborn
W. A. B.

former, with few exceptions, a noble disregard is paid to the doctrines of Vitruvius, and the practice of Palladio and Inigo Jones. The shaft of the column is made sufficiently long to reach a desired point; while its diameter remains unaltered, appearing to have no relation whatever to the composition of the order. The Doric of the Greeks and Romans is used indiscriminately, placed often one above the other without intervening entablature, bases added or taken away, and the mouldings cut and carved in a manner that to any one but those who propagate them must appear monstrous. These absurdities *exist*, but there is not any reason why they should *remain*.

There are many instances in which architectural columns may be employed in machinery with effect and propriety, and the most appropriate use to which they can be put, is to support the entablatures upon which the pedestals of any main feature are secured, as the beam of a steam engine for example; and for the reasons presently to be stated, may be made to deviate to a considerable extent from the proportions of the antique. It is a generally received rule in architecture, "that no support should be burdened with a greater quantity of matter than itself contains;" or, in other words, that the weight placed on a column should not more than equal its own weight.

Now, since the quantity of matter in a cast iron entablature is so much less than in one of stone, having the same strength, may it not be allowable for the same reason, to reduce the diameter of the columns supporting that entablature? When the material is known to be metal, and the surrounding objects are kept in subservience, we may deviate from the antique quite as much as that given in Plate II., in which the modern column, executed in cast iron, was employed for the purpose previously named.

The antique Roman Doric is there divided from the top of the entablature to the base into five portions, one of which is given to the entablature. In the modern example the space is divided into six parts, which may be adopted as the standard.

The two columns noted as irregular in Plate II. are taken from engines of the same kind as that of which the second example formed part. The one with the triglyphs can hardly be called an imitation of any order, it is so vilely mis-shapen: its fellow is evidently an attempt at Roman Doric; but its members are so distorted, and its moulding and details so deformed, that instead of adding beauty to the machine, it excites only ludicrous ideas in the mind of the spectator.

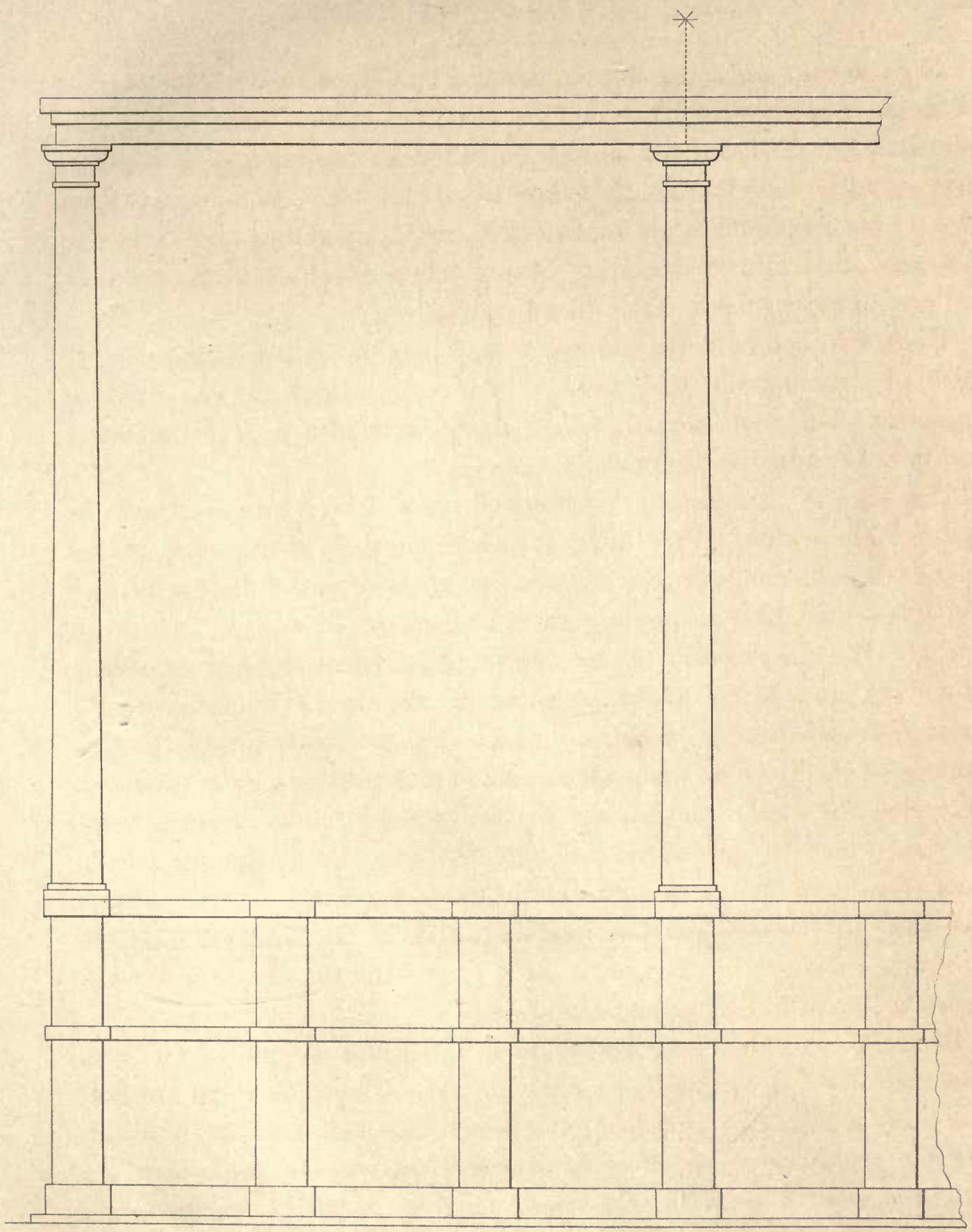
These two columns are examples that may be found scattered very generally throughout the works of our engine-makers who are not engineers; but that marked *modern* is the work of a man of judgment, and may be copied with propriety.

The cost of ill-designed "patterns" in the first instance, and the castings afterwards, differs little, if any, from that of the more perfect model; it is therefore impossible to assign any reason for the use of such bad proportions, and assuredly there is no excuse.

Plate III. is an elevation of part of an "independent engine," consisting of a tank and upper frame supported by six slender columns,—"the usual bedstead-looking machine," which does not even possess the advantage of cheapness to render it excusable that the same style should be continued: the only convenience of the frame running entirely round the top is, that the end of the radius rods of the parallel motion can be fixed upon it without a support being erected expressly for that purpose. But the "overhead" parallel motion, which is the simplest kind, requires only a slight bracket, more easily fitted than the former, even with its advantage of having an entablature.

Plate IV. also shows an elevation of a portable engine of the same power as the former example (viz. 14 horses). These drawings are both to a scale of $\frac{1}{2}$ an inch to a foot; the dimensions can therefore be taken, and the relative weights of each be arrived at with tolerable accuracy. The thickness of metal of the small columns is $\frac{5}{8}$ths of an inch, that of the larger $\frac{3}{4}$ths of an inch, and its entablature $\frac{5}{8}$ths, with a piece of oak timber 2 inches thick fitted in at the bottom; both the tanks

SIX COLUMN INDEPENDANT ENGINE OF 14 HORSE' POWER.



Scale ½ In. to a Foot.

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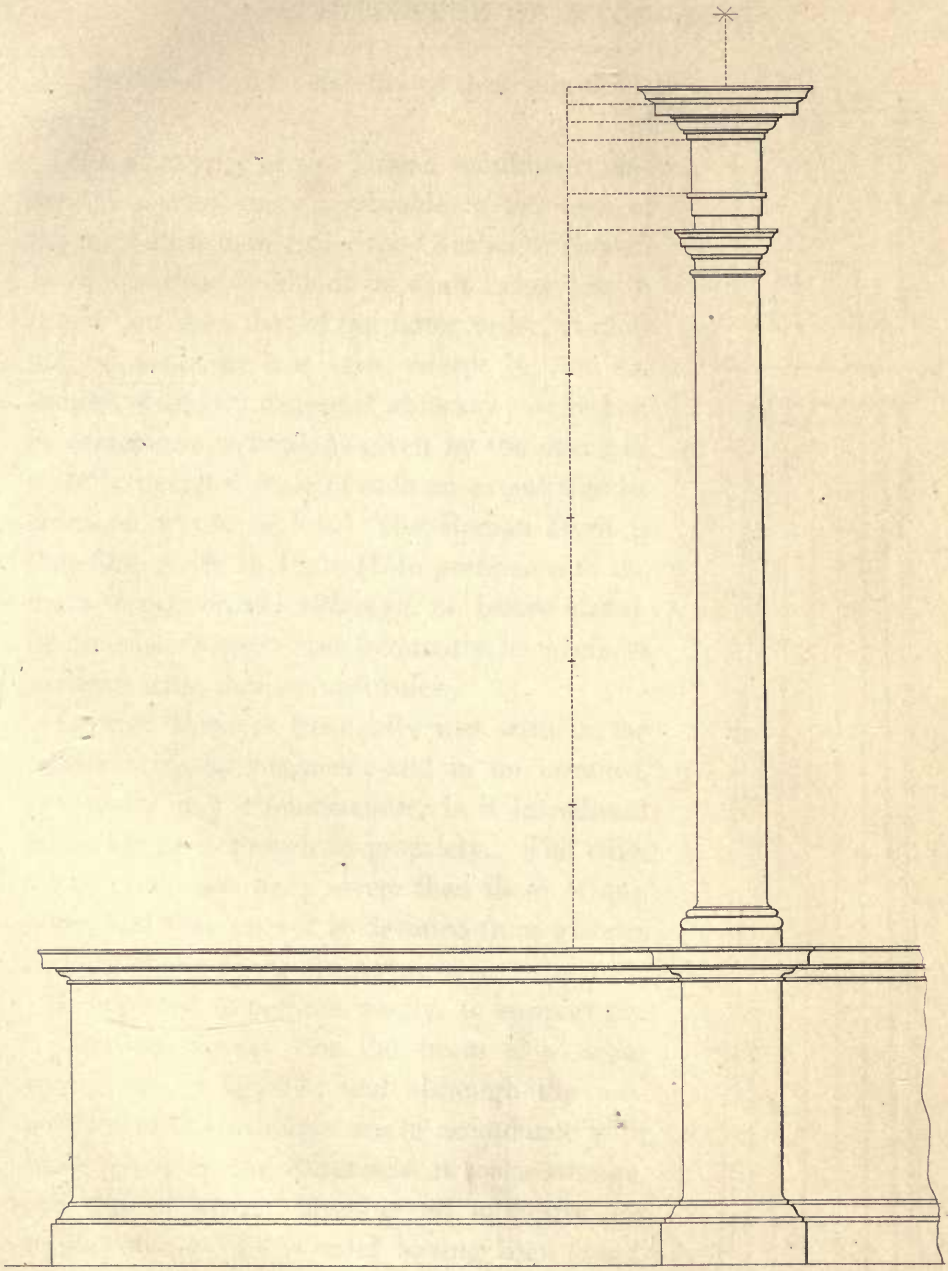
DOUBLE COLUMN INDEPENDANT ENGINE OF 14 HORSE POWER.



Scale ½ In. to a Foot.

John Weale, Architectural Library, 59, High Holborn.

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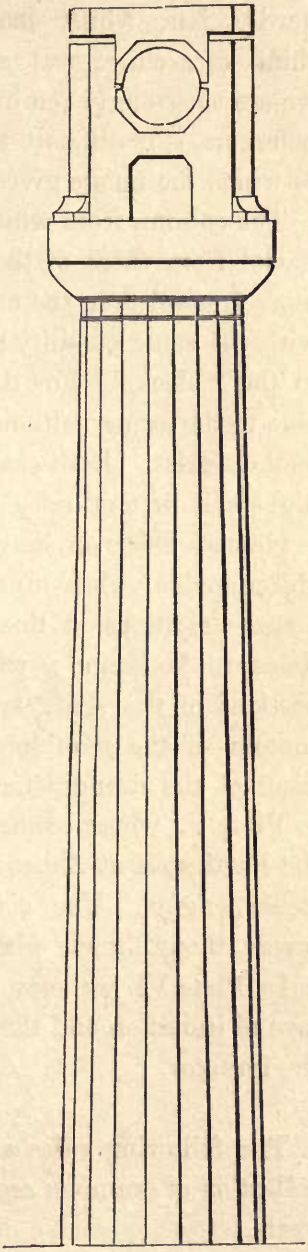
are $\frac{5}{8}$ths thick. The stability of these engines is equal.

The simplicity of the Tuscan mouldings renders this order more applicable to the uses of the mechanist than either the Grecian or Roman Doric; but the height of its shaft being less in proportion than that of the latter order, it cannot be made in cast iron, except in rare instances, with any degree of accuracy; or rather, its correct proportions, as given by the ancients, must be deviated from to such an extent that its character would be lost. The Roman Doric is therefore given in Plate II. in preference to the more simple order; although, as before stated, its dimensions must also frequently be made at variance with architectural rules.

Grecian Doric is frequently met with in the erections of the engineer; and in no instance, nor under any circumstances, is it introduced with even an approach to propriety. The rules for this order are more severe than those of any other, and they cannot be deviated from without entirely changing its character.

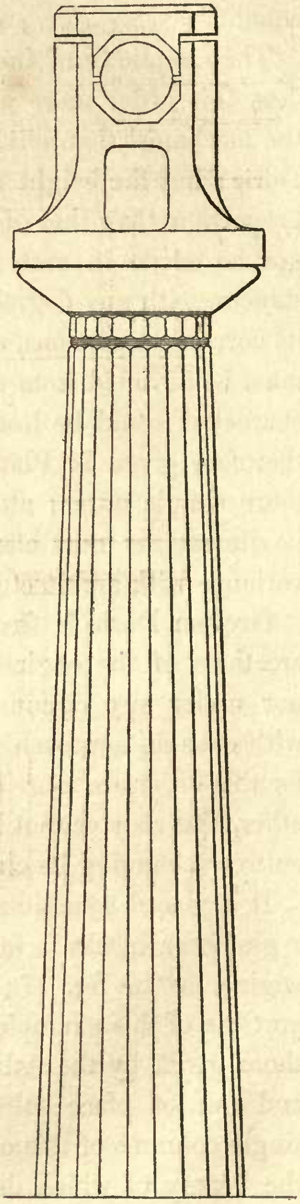
It is placed sometimes singly, to support the "plummer blocks" for the beam of a steam engine, as in fig. 17; and although the proportions of this example are in accordance with those given by the Athenians, it looks strange, and out of place: there is no authority for single columns of this order having been found, the beauty of which depends upon the general assemblage of many features, rather than the

Fig. 17.



contour of detached portions. It is perhaps hardly fair, whilst looking at machinery, to think of architectural arrangement; but when we are so strongly reminded of it by the erection before us, it is difficult to forget the associations to which the image gives rise.

Fig. 18.



The column from which fig. 18 is drawn is a model from those of the temple at Pæstum; is more fanciful than the other; contains less metal, with the same stability; and gives a larger base to the "block." For these reasons it is preferable to the former, although the same general objections exist. [Both examples are from 30-horse high-pressure engines.] (Scale $\frac{3}{4}$ inch.)

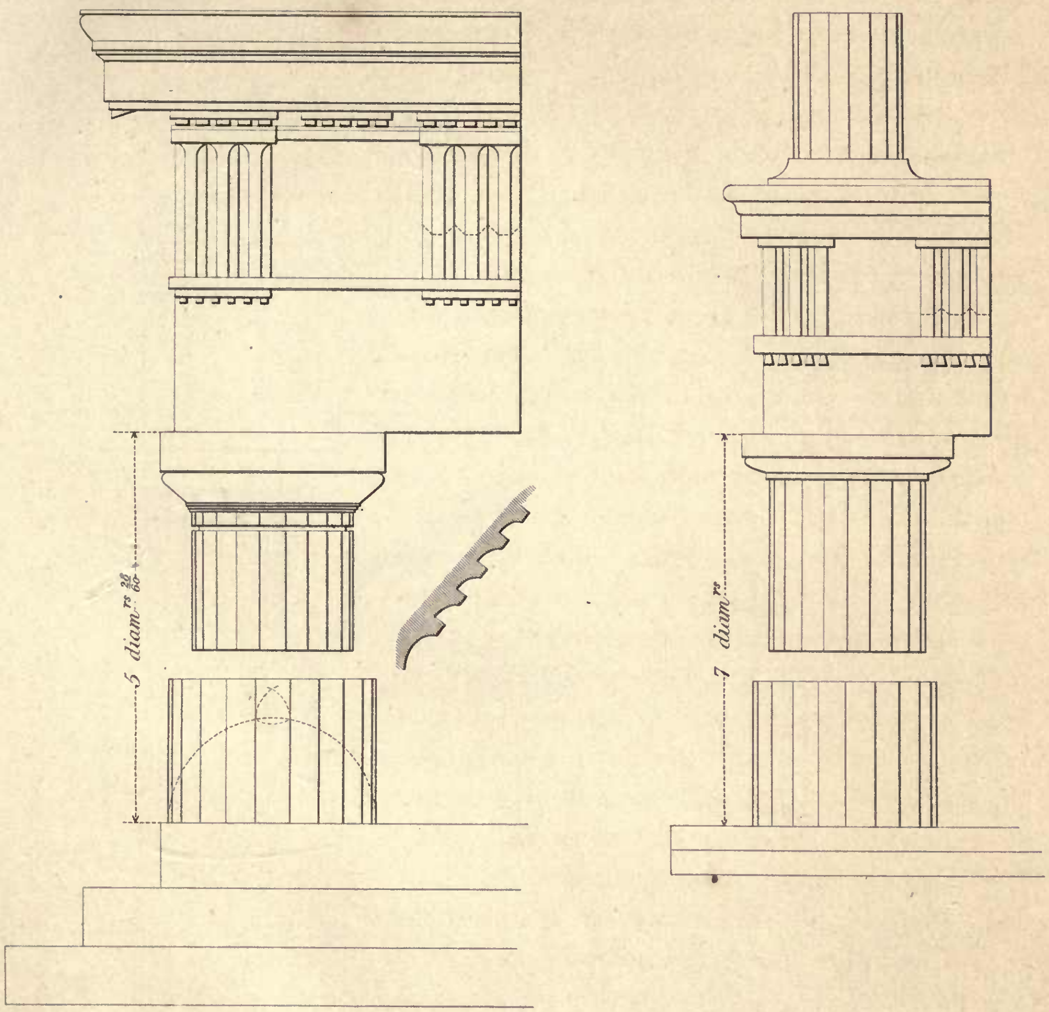
Grecian Doric in its more perfect form being objectionable, what must be said of those distorted imitations of this order which are sometimes to be found; when not only the proportions of the shaft are disregarded, but the contour of the mouldings disfigured under the hand of the draughtsman or pattern-maker, as in Plate V., where, contrasted with a shaft from the Parthenon at Athens, is one from a marine steam engine. The comparison is sufficiently severe, though made without comment.

In Plate VI. we may again see exhibited the love of imitation and the unsuccessful attempt of the imitator.

The following rules are deduced from a large collection of examples accumulated during several years.

CONTRASTED GREEK COLUMNS.

Parthenon, Athens. *Marine Engine.*



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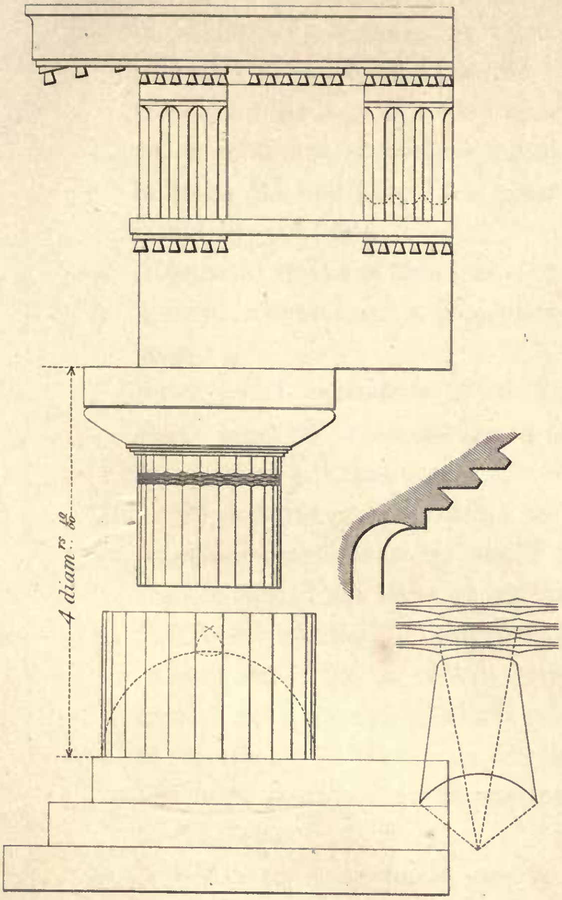
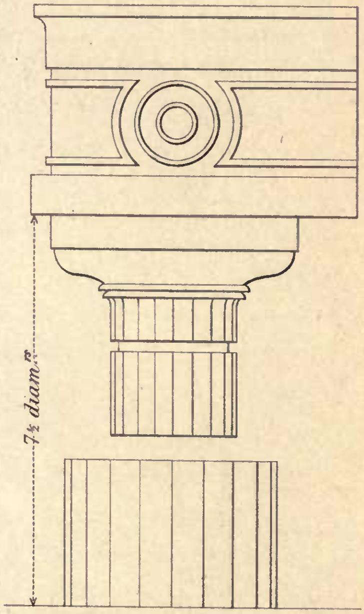
CONTRASTED GREEK COLUMNS.

Temple at Pæstum.



House Engine.

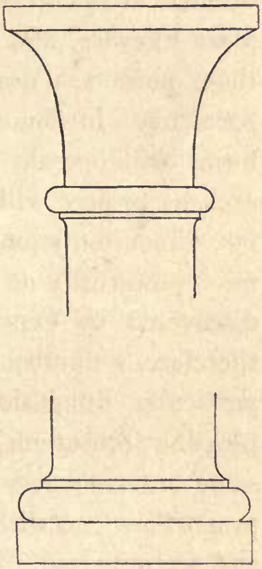


John Weale, Architectural Library, 59, High Holborn.

W. A. Beever

1. A column must never be fixed in any position but the vertical; and unnecessary as this remark may appear, it is not made without cause.
2. A column should never have a less diameter than $\frac{1}{10}$th the height of its shaft. If essential that the support be of less strength than this rule will give, depart from the regular orders entirely, and employ some pleasing curve in the upper member. Fig. 19.
3. An entablature should be equal in depth to between $\frac{1}{6}$th and $\frac{1}{7}$th of the space occupied by it and the column.
4. A pedestal is $\frac{1}{3}$rd of this space, or nearly so.
5. A cornice must have a projection equal to its height.
6. Bases which include a plinth and mouldings above must be twice the depth of the cornice, and project $\frac{1}{3}$rd that depth.
7. Avoid disturbing the outline and direction of principal mouldings by small breaks. Use similar mouldings throughout the work.
8. Triglyphs should be omitted generally, or except in instances where columns are the correct distance apart, which seldom happens in machinery, because they must be placed, not with reference to themselves, but to the parts of the machine they carry.
9. Never make a moveable part to resemble any thing we are accustomed to see stationary.

Fig. 19.



Beyond these limits we can borrow no rules from Architecture that will not lead us into error and absurdity: all we can do with "framings," beams, and cast iron work, which partake of no uniform figure, is to design them with judgment, good taste, and proper regard to those laws

which regulate the actions of forces. "Perfect proportion," if considered only with regard to the relations between the different objects in a composition, and as it merely relates to the pleasure of the sight, seems to consist in this,—that those parts which are either principal or essential should be contrived to catch the eye successively from the most considerable to the least, according to their degrees of importance in the composition, and impress their images on the mind before it is affected by any of the subservient members; yet, that these should be so conditioned as not to be entirely absorbed, but be capable of raising distinct ideas likewise, and such as may be adequate to the purposes for which these parts are designed. The different figures and situations of the parts may in some degree contribute towards this effect; for simple forms will operate more speedily than those that are complicated, and such as project will be sooner perceived than such as are more retired; but dimension seems to be the predominant quality, or that which acts most powerfully on the sense; and this, it is apprehended, can only be discovered by experience, at least to any degree of accuracy. When, therefore, a number of parts, arranged in a particular manner, and under particular dimensions, excite in the generality of judicious spectators pleasing sensations, it will be prudent on every occasion, where the same circumstances subsist, to observe exactly the same arrangement and proportions, notwithstanding they may in themselves appear irregular and unconnected.

It will perhaps be impossible to give an exact definition of the word *Taste*, when employed in the construction of machinery; and it may be judged an useless, if not an absurd undertaking, to lay down rules of caprice, and legislate for whims and fancies. By the word Taste is meant that proper and well-directed exercise of the judgment by which a man acquires facility in detecting impropriety of form, and distinguishing with readiness the masterpieces of great hands from the performances of vulgar artists.

In considering any complex machine, he will examine every distinct

portion of the composition one by one, and reduce every thing to the utmost simplicity: he will deliberate upon the uses of each part, on the forces which will influence them, and on the best means of effectually resisting those forces: he will pass nothing by as insignificant, and condemn nothing without previous reasoning upon its excellences or defects. The capability of thus forming a correct judgment is very much accidental, as it depends upon experience, observation, and a knowledge of practical mathematics.

There may be differences in taste; for the same causes do not operate with equal effect on the minds of all. But the *principles of taste* do not differ, because they operate by principles in nature, and which are not derived from any particular habits or advantages. Prejudice derived from a defective education may give a colour to the mind, through which medium deformities may seem beautiful; from a long and close attention to a certain object the imagination may be cramped and confined in such a manner that nothing pleases it beyond the narrow limits to which custom has bound it. This may influence the *degree* of taste, but it does not affect the *principle*. It is upon these principles of taste that the ideas of perfect beauty are founded, whether in nature or in works of art; and it will be found that beauty of proportion in machinery is sequent upon the use of those figures which possess the greatest strength with the least possible matter. A little attention will convince us that this must of necessity be the case.

It is painful to contemplate a huge mass of matter sustained upon such slender supports that they bend and totter under it; or to see a feeble stop opposed to overwhelming force. These are extreme cases; the sensations they produce are extreme likewise, and are apparent to the most unpractised eye. A different feeling is generated when we see prodigious strength opposed to yielding weakness, or gigantic props beneath a light superstructure; and it is frequently as painful to be thus excited to ridicule as to fear. As these absurdities vanish and approach more nearly to propriety of proportion, the difficulty of distinguishing the faults

increases in the same ratio. If the excess or diminution be not glaring, it is only a practised eye can discover inaccuracy, but it is for such eyes that we must work; and while we remember that beauty may be seen and appreciated by the commonalty, let us not forget that the silent approval of those whom we consider masters is more estimable than the loudest praise of the vulgar. The latter will be guided by the eye alone, but, with the former, judgment and reason will unite in the decision.

The part of the engine which first presents itself for consideration is the framing, and the laws of statics will be found to combine with those of taste in the production of a good design to so great an extent that they will appear dependent upon each other.

The effect of forces upon framings, as they are usually applied, is to compress them in the direction of their length. Therefore their parts should be disposed in *straight lines*, so arranged that, whilst transverse strain is avoided, each separate single force, or the resultant of any number of forces, is opposed by some portion placed in the same direction with it.

The dimensions necessary successfully to resist any given stress are arrived at theoretically by very simple means, and when this force is constant, and uninfluenced by jerks, the *calculated* result may be relied upon without fear of failure. In machinery the dynamical effects of forces are constantly varying, and it requires much well-directed thought to enable us correctly to determine the quantity of variation.

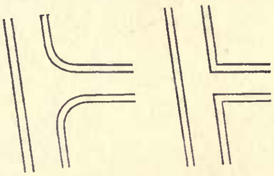
The greatest power the engine is capable of exerting, the momentum the parts put in motion acquire, the leverage at which the opposing forces act, and the impediments or checks to which the machinery is liable, are the chief points on which to found the data of our calculations. But the re-action occasioned by sudden opposition to the impulsive power is often greater than that power, and the parts which are secured from yielding would be liable to fracture were the dimensions of them furnished by theory alone.

Beauty of form and proportion are therefore both evidently dependent

upon the proper adaptation of those rules which are gained by experience and a well-directed judgment.

The principal thing to be guarded against in the design of a framing (or any feature possessing considerable extent of surface) is sudden variation in the direction of a member. There is no particular line which is always found the most beautiful; if there were, it would be easy to give a rule for curves or form; but we seldom see natural objects entirely angular, and those most pleasing to the eye swell or sink so gradually that it is often difficult to ascertain the point of their beginning or end. A reason for this may be that a sharp angle causes a momentary surprise from the sudden change which is exerted upon the eye, and is therefore displeasing. Fig. A.

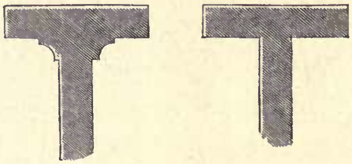
Fig. A.



The *direction* of a varying dimension must be guided by statical laws, and the evidence of its propriety be left to the judgment.

There are exceptions to this as to most other general rules, for boldness of outline (a very essential requisite in composition) is often produced by sudden projection, and this can only be made with an angle (fig. B); still this angle may be formed in a graceful manner.

Fig. B.



The degree of its inclination will be regulated by the direction of some force which may be here presumed to operate against it; and as an exception to the rule, it may be said, that if this direction be evidently arranged to oppose some strain, it will be *correct*, though perhaps not actually graceful. These circumstances are constantly occurring in practice; and knowing this, some may smile that any attempt at maxims should be made. But there is a great margin for regulation; and even amongst those necessary deviations, some guide derived from previous observation is certain to present itself.

This may be further illustrated by reference to the drawings, figs. 20 and 21, which are framings from 20-horse land engines: they neither

Fig. 20.

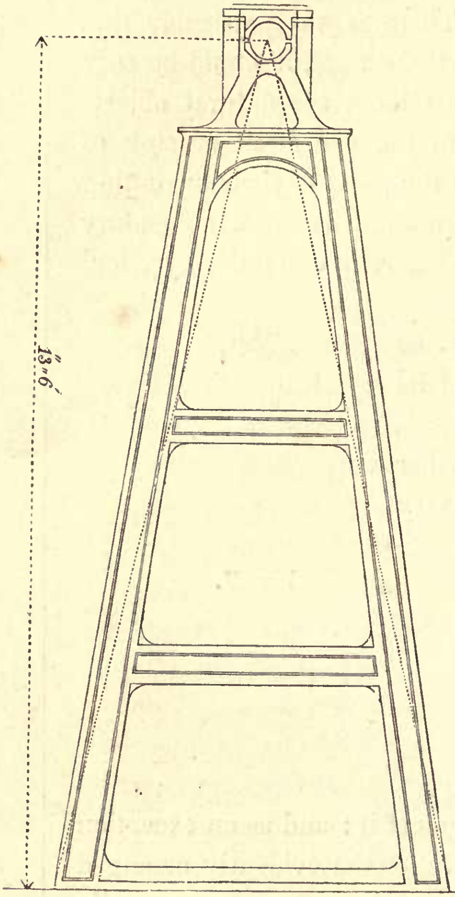
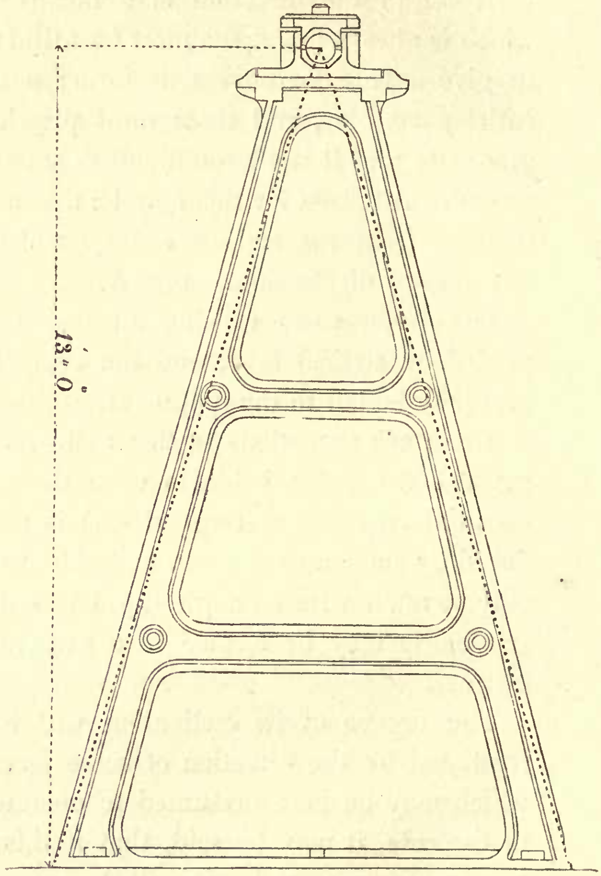


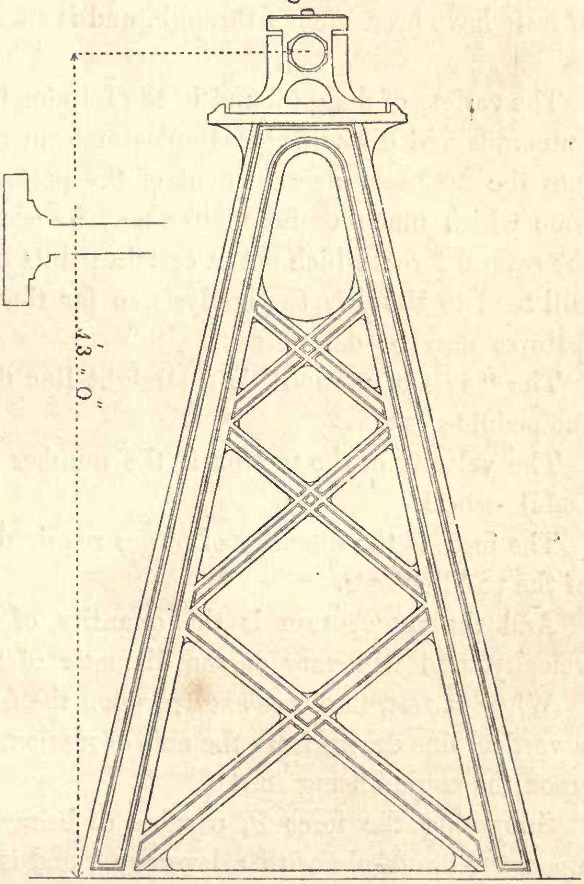
Fig. 21.



of them have much claim to beauty, but the most pleasing design is certainly that in fig. 21; because, in the first place, its mechanical proportions are more correct, the main limbs are made gradually stronger as they recede from the centre of vibration, and become more affected by leverage, and they are arranged so that a straight line is opposed to the

force. The other example, on the contrary, exhibits neither of these requisites; the consequence is, that the engine is exceedingly unsteady, often out of repair, and is noisy. This *design* abounds in sharp angles and crude proportions without gradation, which do not occur to nearly so great an extent in the other framing, the angles of which are rounded off, and the same feature extended throughout. The ladder-like figure possessed by both is not a pleasing one, though so often employed in cast iron work. If made with timber in the same way, the "truss" (if it may be called one) would tend to "rack" under the influence of the vibratory motion communicated to it by the beam; and notwithstanding that the principle has been denied, the same rule by which a truss of timber is framed ought to some extent to be considered in the formation of an iron one, as the mathematical demonstration is the same in both cases. For the limb opposed to the upward stroke of the beam will tend to become vertical, and is restrained by the cross pieces of the frame, which being of cast iron, ought not to be exposed to a tensile force. In proof of this assertion the annexed framing, fig. 22,

Fig. 22.



from the hands of one of our greatest engineers, is given, which exhibits a complete "truss;" and it is conceived that the excellence of this mechanical arrangement will be at once admitted. The good taste shown in this design arises from the use of "propriety of form." The angles are frequent, but similar, and disposed uniformly over the work. The eye may range along the lines without being checked by sudden breaks, and the entire contour is bold and pleasing.

A better illustration of "boldness of outline" can hardly be given. It is devoid of that gradual undulation generally admitted to be beautiful where properly introduced. Many of the rules laid down by professors of taste have been broken through, and it stands an elegant exception.

The variety of design found in the framings of marine engines furnishes numerous and diversified examples of form and dimension. An inquiry into the necessary arrangement of the parts will lead us to conclusions from which much useful matter may be gleaned; and the reduction of the several forces which act at certain points into their common resultants, will tend to simplify the analysis so far that the direction of the main features may be determined.

The "axis of motion" is a straight line drawn through the centre of the paddle-shaft.

The velocity of the motion is the number of revolutions made by the paddle-wheel.

The force is the quantity of power required to overcome the resistance of the paddle-floats.

And the momentum is the quantity of matter multiplied into the velocity, and will vary as the diameter of the wheel.

When at rest, the force exerted upon the framing is in the direction of a vertical line drawn from the axis of motion, but is changed immediately upon the engine being started.

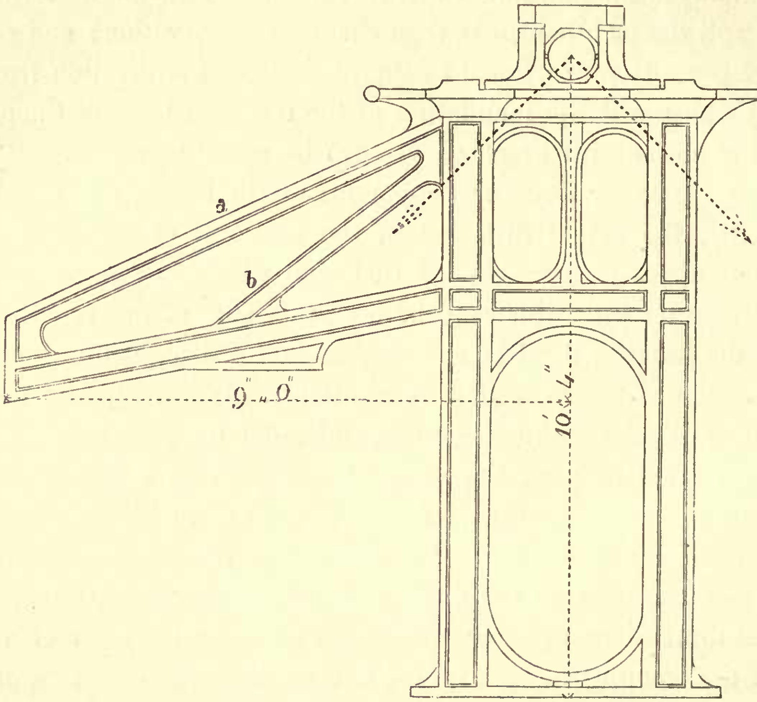
Supposing the force P, capable of being exerted by an engine, acts upon the crank-pin with a leverage l, and is resisted by the paddle-float,

equal to a quantity R, with a leverage L; then P : R : : L : l. Suppose, again, the crank and the paddle-arm to be in the same straight line, they will act as a lever of the second kind,—the float being the fulcrum, the crank-pin the power, and the paddle-shaft the weight; and the direction of the resultant of the two forces will be common to the angles formed by the crank and the paddle-arm as they change their position; and as each force is reciprocally proportional to the distance of its direction from the fulcrum, so also will the inclination of the resultant towards the greater force (or the power with greater leverage) be exactly proportional to its excess over the lesser force or same power with less leverage. As the engine starts, the actual direction of the resultant of these two forces will depend upon the situation of that line which is a mean between the two cranks; and as this may be on either side of the vertical, some feature of the framing must be arranged so that a straight line is opposed to the direction of the force of this resultant. Again, suppose that the base of the vertical framing is immoveable, and the part secured to the cylinder immoveable also, the entire structure would tend to vibrate backwards and forwards, with a leverage equal to the height of the axis of motion from the dead plate. The opposition this motion meets with when it inclines towards the cylinder is always ample, (supposing, of course, the dimensions to be correct,) but in the contrary direction, that portion of the framing being exposed to a tensile force, a foot beyond the base is requisite, to act as a strut; it being far preferable than allowing the pull to be upon the cylinder. The framings of all our best engines are thus arranged; and it may therefore be considered essential. When the framings of both engines are secured to each other, and form as it were a single fabric, other facilities for giving stability present themselves, and the "foot" may be reduced; but considered separately, the framings evidently require to be thus supported, and the above observations will apply to independent structures where opportunities for giving transverse stiffness do not occur.

The same relative proportion being supposed to exist between the

leverage of the crank and paddle-arm, the vibratory motion of the framing will be nearly in the directions of the dotted arrows in fig. 23. The resistance against its inclination towards the cylinder is evidently

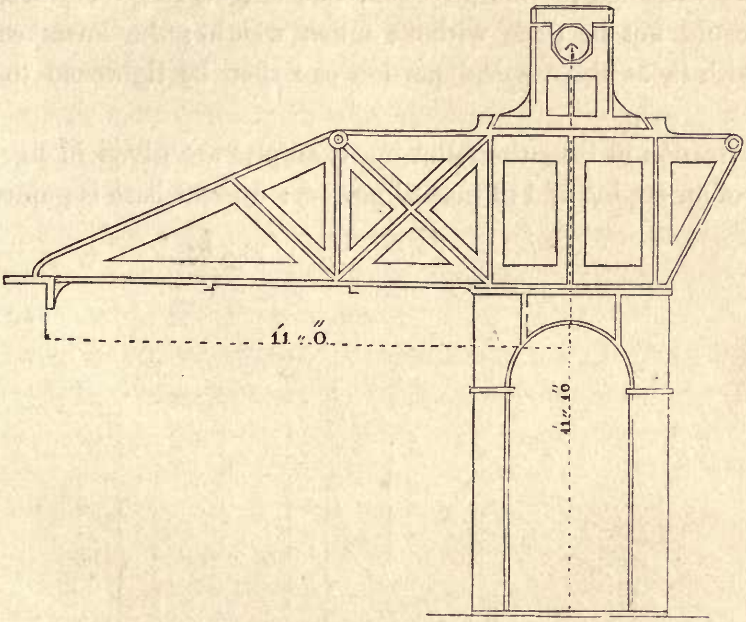
Fig. 23.



sufficient; in the contrary direction it is defective, and therefore the deficiency in the quantity of power required is made up by a pull upon the cylinder and condenser, to which parts the braces *a* and *b* are bolted. The "mechanical proportions" of this design are consequently faulty. The propriety of its form as regards "taste" cannot be called good, though it has considerable merit. In some parts it is bold and effective, in others it is crude and irregular; but it may be taken as a framing of more than average excellence, since, where there is one better, there are two worse: perhaps its chief merit may be the absence of architectural ingenuity.

Fig. 24 is the framing of a 60-horse engine; it has precisely the same defect in its mechanical construction as the last example, but without

Fig. 24.



so much beauty: the angles in its composition are sudden and dissimilar, the direction of its features change abruptly without curves or gradation, and the truss is not carried out. " Changes of form in any system of framing almost always increase the power of the weight, and often produce cross strains that are attended with the worst consequences, when such changes are not foreseen and provided for accordingly."

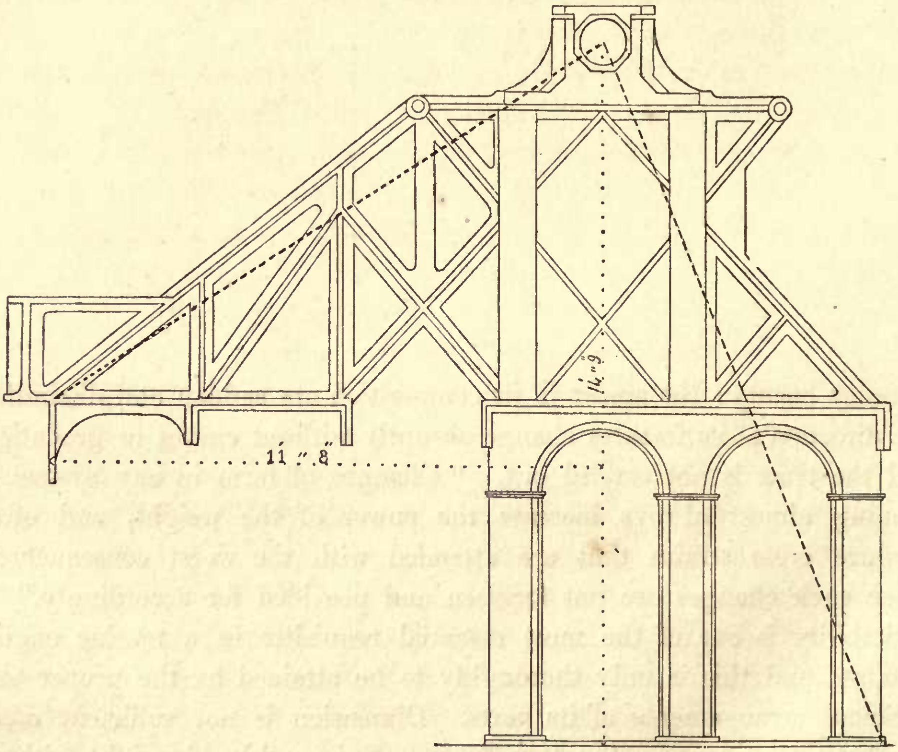
Stability is one of the most essential requisites in a marine engine framing, and this is only thoroughly to be attained by the proper and judicious arrangements of its parts. Dimension is not sufficient *alone* to effect this: quantity of matter, if misapplied, would add weight, without being of any service whatever. Every thing that tends to increase stability, without increasing the weight of metal, is advantageous in a

mechanical point of view; and it can be demonstrated, that a part so added will, as regards propriety of form, be beautiful also.

It is not intended to be implied that the entire system of framing should be extended in this direction, but only a single feature, for the former could not be done without much weight: the latter carries no defects with it, as the vertical portion can then be lightened to a great extent.

In illustration of this, the following examples are given in fig. 25 (the framing of an engine of 110 horses' power): a great base is gained by the

Fig. 25.

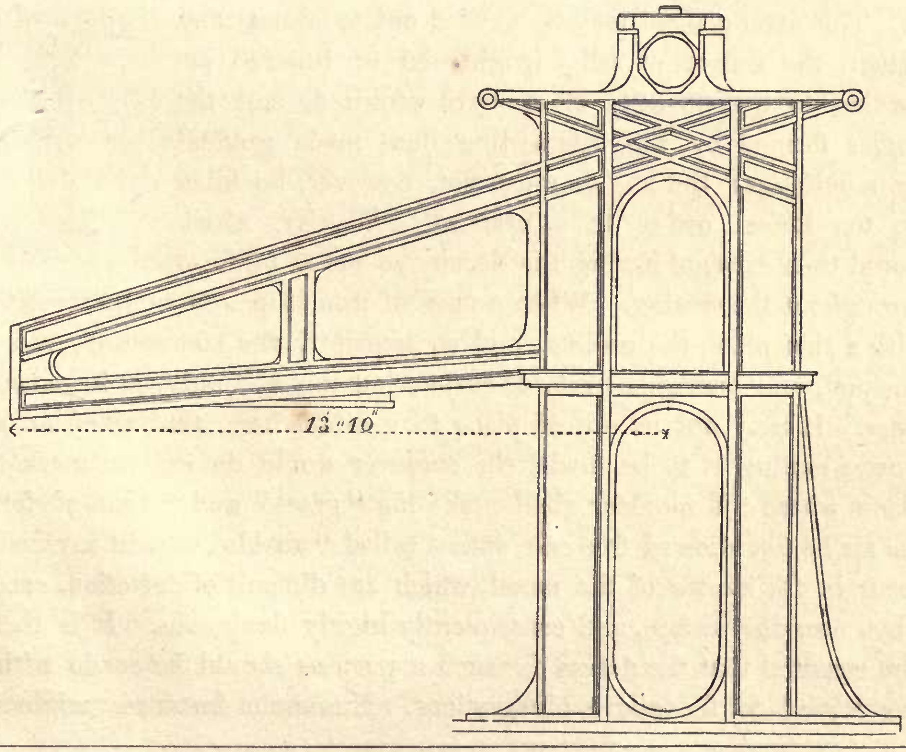


addition of a truss opposed to the force acting in the direction of the dotted line drawn from the axis of motion to the "*foot*" of the frame.

Now, since the greatest resistance offered to any weight is when a straight line is opposed to it, the parts on the outside of the dotted line are inappropriately employed; therefore the form is not correct, and the eye is unpleasingly affected. Respecting the remaining portion of the design, it is crude; the angles do not compose, from the sudden change in the direction of their lines; the truss is not in direct opposition to the thrust, and the boldness which the outline might possess, were the idea arranged with "taste," is completely lost. It is a system dislocated and broken up, a compilation of mechanical arrangements loosely and negligently thrown together. The engine is certainly firm; but the quantity of metal used is much greater than with a different arrangement the same amount of stability might be secured.

The framing, fig. 26, is from an engine of the same power us the last

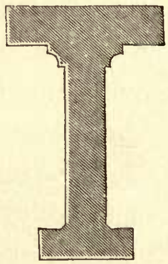
Fig. 26.



example. The reason for the disposition of each feature is immediately apparent; the propriety of arrangement and form gained by the well-directed adaptation of scientific rules is here made manifest. The parts through which the power acts are carried as nearly as practicable in right lines from the points of resistance to the centre of motion. The dimensions of the various portions are regulated by experience, and the work is simple and elegant. The stability of the engine amounted to perfect non-vibration; and the reason undoubtedly is, that the action of the power passes from particle to particle of the metal in the same direction: for it is always the change in the direction of a force, or, which is the same thing, change in direction of the resistance, that causes vibration.

In the foregoing examples, ornament is produced by *relief*, not decoration. The cross sections of all the members are in the form represented in the annexed diagram (fig. C), or some modification of it. This arrangement may be carried out to almost any extent, the degree of relief heightened or lowered according to the quantity of strength required, and the angles formed by the intersecting lines made gradual by mouldings: the angles must not, however, be filled up too much, owing to a practical difficulty, which would then exist, of having the density of metal uniform throughout the casting. When a mass of iron is placed in juxtaposition with a thin plate, the cooling, and consequently the contraction, will be unequal, and breakage likely to ensue; but this will only be in extreme cases. It may not be out of place to mention here, that when an extensive casting is to be made, the engineer would do well to mark the places where the moulder shall make his "gates" and "vents;" for if the air be not allowed free exit, spaces called "air-blows" will invariably occur in the centre of the metal, which are difficult of detection, except when near the surface, and consequently highly dangerous. It is therefore essential that the design for such a purpose should be made with a due regard to the above observations. Numerous instances might be

Fig. C.



quoted where accidents have occurred solely from these causes; and here again it is apparent that theory, without her companion, experience, would be liable to error and accident.

Marine engine framings are by very common consent devoted to the display of architectural ingenuity, and it would be difficult to find any engineering work less appropriate for such arrangement. It must not be thought that these remarks are made invidiously, or that the designs are exhibited with the intent to ridicule: the purpose is far removed from either of these; and difficult as it may be to point out error without giving offence, it is nevertheless trusted the end will justify the means by which it is attained.

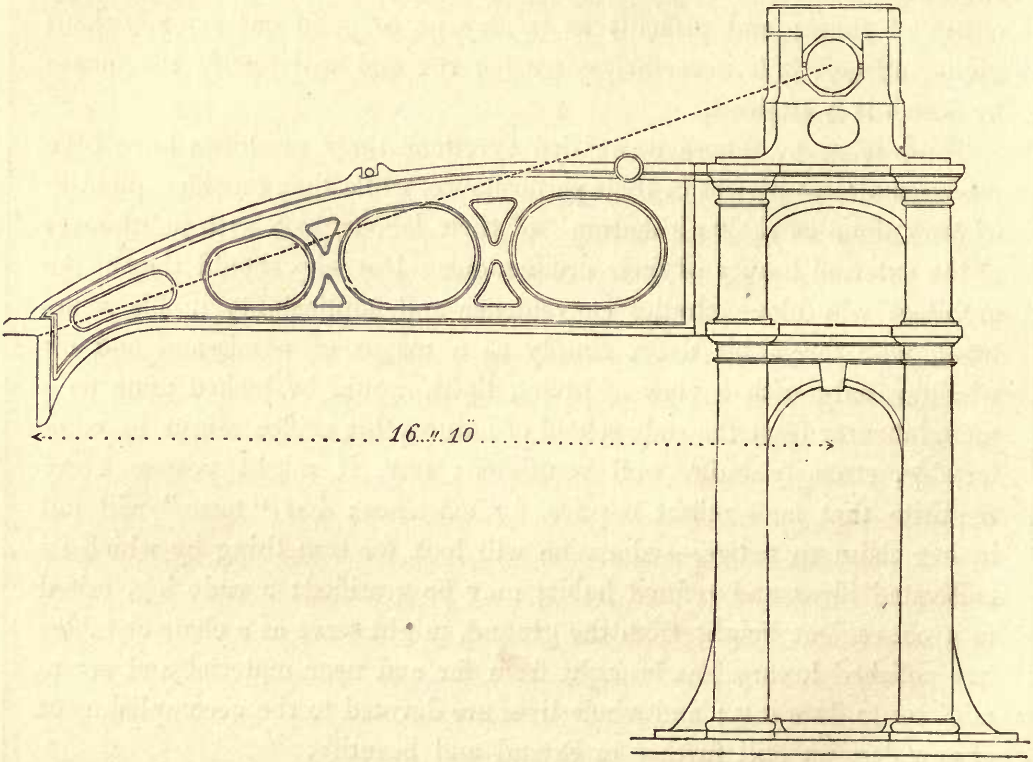
Those men, by whose unwearied exertions these machines have been rendered almost perfect in their performance, while they consider quantity of work done as the "ultimatum" of their labour, look with indifference at the external beauty of their productions. But why should they? An architect who alone studies convenience and applicability in his structures, who forms his doors simply as a means of admission, and his windows only with a view of giving light, would be looked upon as a mere labourer from the rude school of nature: his edifice might be comfortable, strongly built, well ventilated; nay, it might possess every requisite that man might require for existence; but "taste" will put in her claim to notice,—education will look for something by which its cultivated ideas and refined habits may be gratified: a rude log, raised to a convenient height from the ground, might serve as a chair or table; but polished luxury has brought from far and near material and art to minister to its wants; and whole lives are devoted to the accomplishment of new designs, still further to extend and beautify.

Why then should externals be disregarded in those things which constitute a real good? It will be said, perhaps, they are not neglected: the answer must be, if the attempt has been made, the result has proved a failure. Why have volumes been written to prove, that, to be beautiful,

certain proportions must exist in certain figures? and why should these same figures be employed with different proportions, while the possibility exists of forming them after the received rule? There is no reason, argue as we may; nor excuse either, however logically the argument may be treated.

Fig. 27 is a framing from an engine of the nominal power of 142 horses, (60-inch cylinder, 6-feet stroke). The dimensions of the vertical

Fig. 27.

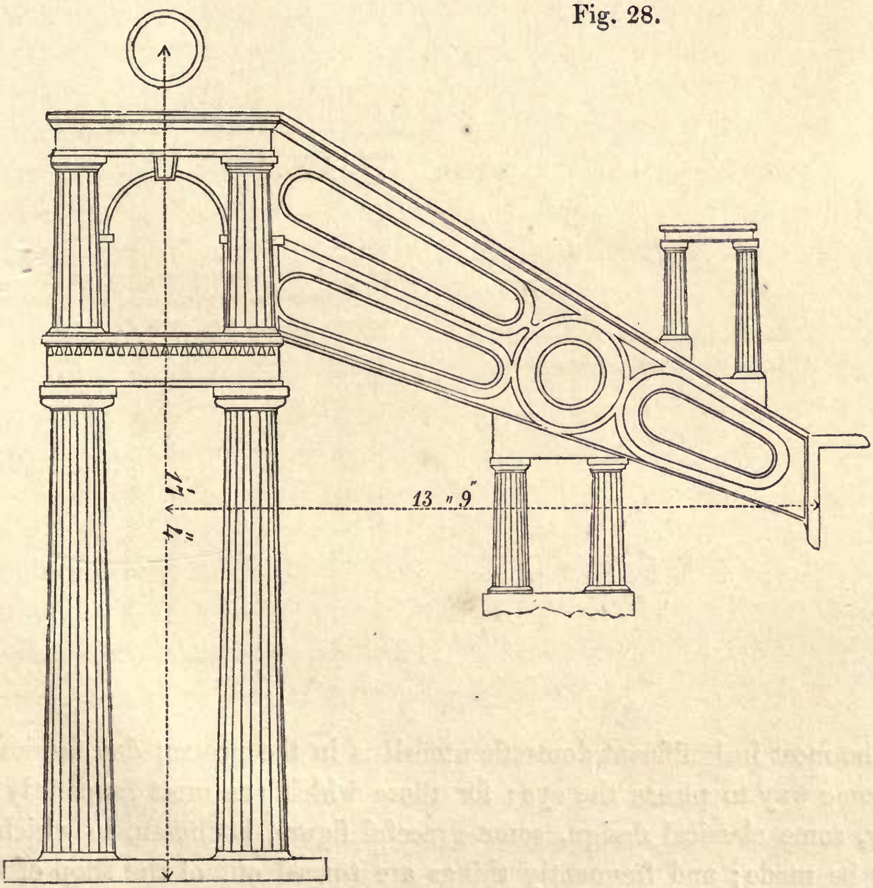


and transverse frames bear no proportion to the relative strains which go through them. The curved line of the latter is contrary to every statical law, for every force acting in the direction of the chord of the arc would tend to break it with a leverage equal to the versed sine;

and hence, to make up for the extra resistance, more metal is necessary, and consequently more weight. The supposed necessity of this form was evidently to enable a large condenser to be erected; but the ingenuity of the artist must have been at a low ebb indeed if he could find no other means for its introduction than the distortion of his framing. With reference to the vertical portion, it may be designated a very usual imitation of architecture as applied to enginery, except the huge mass of metal in the plummer block, which is unusual.

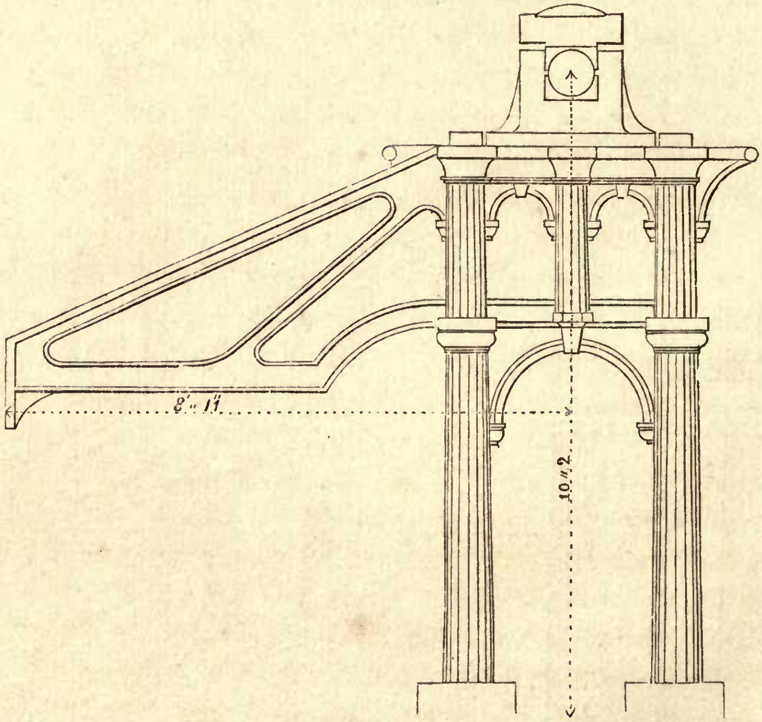
The three following drawings (figures 28, 29, and 30,) represent a

Fig. 28.



favourite style of composition, in imitation of the Grecian Doric; but the two last stand very far above that framing shown in fig. 28, the design of which admits of no comparative expression,—it is "hideously ugly." It has been before observed, that this order is singularly inappropriate to this purpose, even if in the execution of the model the detail were faultless; but in these, every feature is distorted to render it applicable to a purpose, for which nothing but the strictest attention to form and dimension can produce either beauty or propriety.

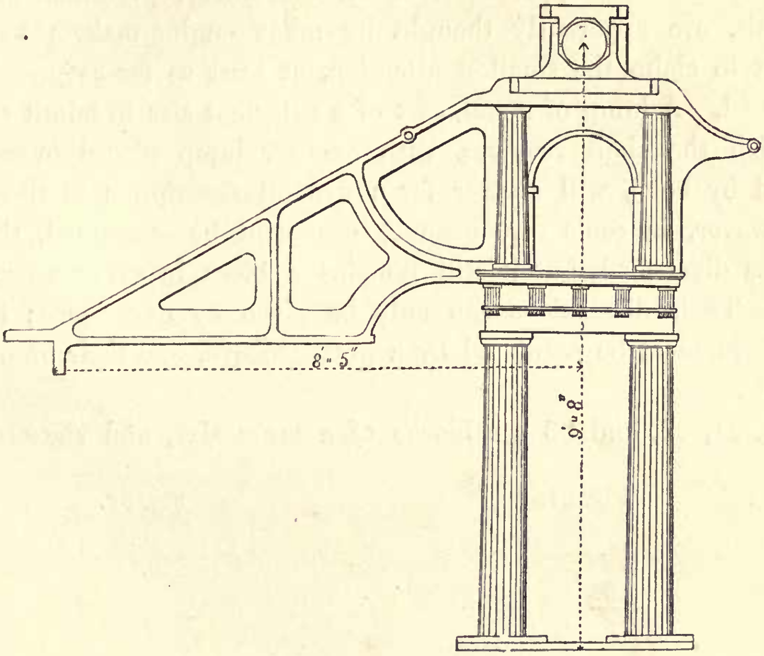
Fig. 29.



The most insignificant domestic utensil is in the present day fashioned in some way to please the eye: for those which are most frequently in view, some classical design, some graceful figure, is chosen, in which it may be made; and frequently things are turned out of the shop of the

simple coppersmith of as beautiful proportion as those from which they were copied. How then can the engineer, who often is, and invariably ought to be, a man of education, suffer such absurdities to exist as we constantly see in the productions of his labour? He cannot *lead* where he

Fig. 30.



attempts an architectural order, for ages have consented to receive the proportions given by the ancients for their five, nor has a sixth yet been produced; and if he cannot even *follow*, let him eschew the fashion of architecturalizing his machinery, and content himself with studying the more efficacious method of framing given in the first part of these observations.

To turn to another practical point. It may be observed in several examples, that the flanch of the transverse frame is made to bolt on to the top as well as to the sides of the cylinder; but as a bolt can only

be efficaciously employed to resist tension, those which pass through the top are useless; they become affected by a constant alternating thrust, and pull and "work loose;" a slight lip to rest the frame upon while fitting is all that is required.

Those stationary appendages to all machinery, plummer blocks or pedestals, are apparently thought by many engine-makers too insignificant to claim the smallest attention, at least as far as proportion is concerned. A lump of metal, cast of a sufficient size to admit the brass in which the shaft revolves, with another lump placed over it, and secured by bolts, will answer for a general description of these parts. If, however, in some rare instance ornament be attempted, the block becomes diversified, but it still remains a block in every sense of the word. Their dimensions can only be given by experience; therefore their form must be regulated by a practised eye, and their propriety by example.

Figs. 31, 32, and 33 are blocks of a large size, and show different

Fig. 31.

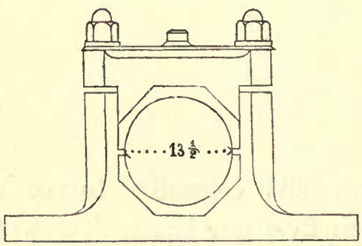
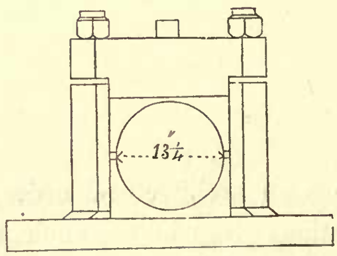


Fig. 32.



arrangements. The first is met with in the better class of work, but has fallen considerably into disuse, from the difficulty, or rather the expense, of fitting the brass properly on its bearings.

Fig. 32 is seen in Millwright's work: it stands far below the former in point of shape, and is both weak and poor at the angles of the base.

Fig. 33 has superseded or is fast superseding the other kinds of

block, and is evidently more appropriate for its purpose. The iron base and cap are fixed in their position, and bored out; the brass is turned and accurately fitted, and then bored out concentric with the outer circle; the bolts are also turned and fitted into bored holes, which take a portion of the brass, and serve as keys: this mode of fitting, which is both cheaper and more accurate than the older plans, with octagonal or square brasses, will no doubt eventually be brought into general use: it has also the recommendation of character, and the capability of being made of very pleasing form. For instance, if the pedestal be high, the base may be extended by a gradual curve in the moulding to any dimension, without increasing the weight of metal; and the form of moulding may be struck to coincide with any that may be employed in the other portions of the machinery of which it forms a part. The figure is taken from two examples of this kind of block.

Fig. 33.

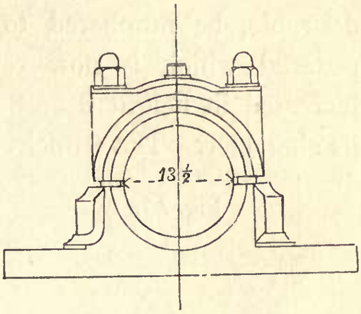
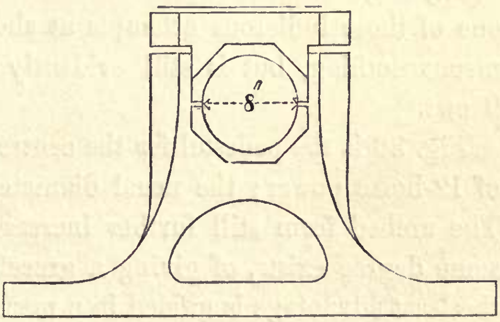


Fig. 34 shows a pedestal from a 50-inch cylinder pumping engine: the curve uniting the vertical part with the base, it will be perceived, is gradual, and more sharp as it joins the horizontal plate; and it may be observed here, that segments of circles should never be used in "rounding off;" they are always formal, and devoid of that elegance which the sweep, if properly arranged, must possess. Workmen are sure to use their compasses to strike out a curve, unless expressly forbidden to do so.

Fig. 34.



The drawing office is furnished with moulded curves of a size suitable to the smaller scale to which the draughtsmen work. Would it not be well to have the same curves increased to full-sized dimensions, and made of sheet iron, for use in the pattern shop? There would then be a certainty of the intended design being carried out. These curves may, if thought desirable, be numbered to correspond with those in the office. The pedestal which is now referred to is exceedingly good, and may be increased in height 6 or 8 inches, with the same curve, and still retain its character. The semicircular recess is 3 inches deep on each side.

Fig. 35.

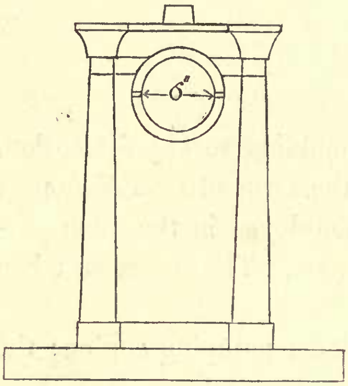


Fig. 36.

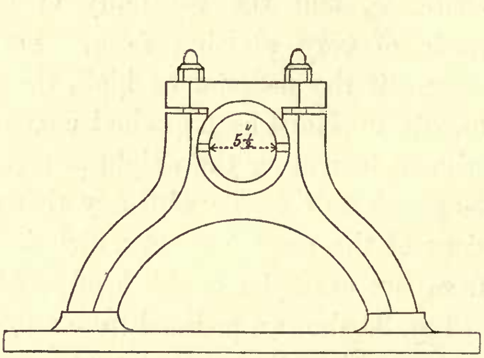


Fig. 35, which is a pedestal from a 45-horse land engine, represents one of those ludicrous attempts at show that have been referred to. It means nothing, but is still evidently an attempt: its weight is nearly 9 cwt.

Fig. 36 is the pedestal for the centre gudgeon of a beam for an engine of 12-horse power; the usual diameter, if of cast iron, being $3\frac{1}{2}$ inches. The arched form still further increases the difficulty, which always to some degree exists, of giving a graceful form to these features, and not the least advantage is gained in a mechanical sense.

Fig. 37.

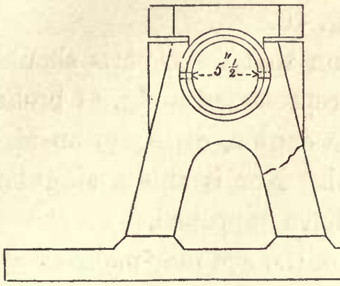


Fig. 38.

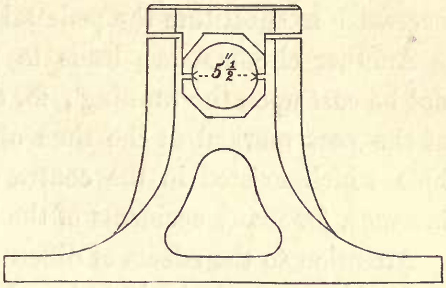


Fig. 37 exhibits a pedestal from a 25-horse engine, which broke at the part marked, owing to an "air-hole" in the casting. The lines are formal and shapeless; it was replaced by the block represented in fig. 38, which is of a better figure, but still not perfect.

All the five last examples are for the bearings of the centre gudgeons of beams.

On smaller pedestals, which support the bearings of the starting gear of marine engines, for instance, and from which the three following examples, figs. 39, 40, and 41, are taken, it is only necessary to make two remarks, given rise to by occurrences which theory cannot account for.

Fig. 39.

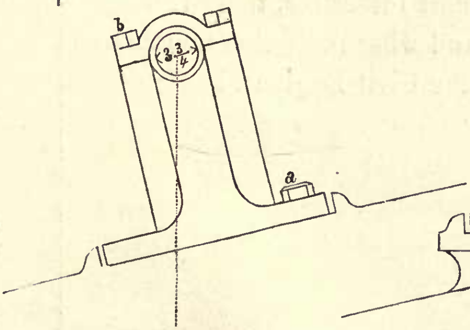


Fig. 40.

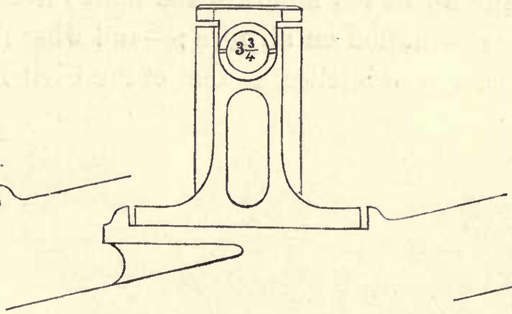
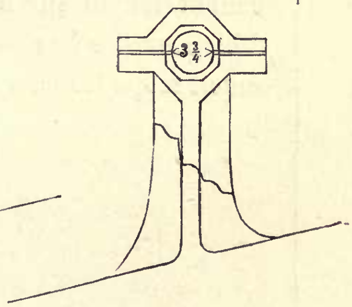


Fig. 41.



In fig. 39 the pedestal is fixed in a sloping position, very properly if the force applied to the starting lever acted always in a contrary direction; but such not being the case, the pedestal in the case here quoted constantly

became deranged by the bolts *a* and *b* working loose; so that it was found necessary to substitute the pedestal shown in fig. 40.

Another circumstance leads to the conclusion that these parts should not be *cast* upon the framing; for the pedestal represented in fig. 41 broke at the part marked at the time of starting the engine, owing to an air-hole which existed in the centre of the metal. Nor is this a singular instance, for many accidents of the like nature have happened.

Attention to the effects of different forms upon the eye may make every detail, however insignificant, subservient to the rules of "taste," and pleasing under circumstances which would render others intolerable: practice will enable us to portion out the different degrees of relief or ornament necessary in the various parts of machinery with great facility: a well-directed judgment will point out to us the reasons why the means employed should produce the required end: and these, combined with theoretical knowledge, will render it a task of delightful labour to design and execute. Nothing grows so much upon us as the love of our profession, when once the way to reasoning upon its advantages is opened: each new thought discloses some new path leading to greater imaginings, and still we are led on;—emulation, the desire of excellence, and the knowledge we acquire of our own powers, are fascinating impulses which cannot fail to stir up in the minds of the most insensible, those feelings which nature has engrafted on all men;—and what profession affords so much scope for energy of intellect as that of the Civil Engineer!

In the practical operations connected with the strength of beams for steam engines, that sectional area which would be found by calculation is never thought sufficient, and every one adds to it as he thinks necessary; hence results the variety in the strength of beams for engines of the same power, the velocity and length of leverage remaining constant.

The examples here quoted, with a view to furnish proper dimensions, are from engines that have been at work at least thirteen years, and one twenty-five years.

It has been remarked, (but upon what data we shall not stop to consider,) that it is impossible to tell if the parts of a machine are strong enough until they have been at constant work for a year; the reason given being, that the total amount of deflexion will not be arrived at before. It is needless to say, that this is an absurd dogma; for if a force permanently alters the shape of a beam, it may be considered as broken.

We are at no loss at the present day for data on which to found calculations for the theoretical determination of the load any form of beam will carry, in whatever part and in whatever direction the force acts, or whether it be stationary or moving. Therefore, the only difficulty, (if it can be called one,) seems to be in the determination of the quantity of weight that is actually applied to the end of a beam.

If a cast iron beam, 1 inch square, and 1 foot long between bearings, is capable of supporting a load in the middle of its length and at rest, equal to 900 lbs., one double that length will only support $\frac{900}{2}$ or 450 lbs., or nearly so; but if it be double the depth, with the same bearing, it will carry $900 \times 4 = 3600$ lbs.; if it be double the breadth, with the same bearing, 900×2, or 1800, will be its load; and this is self-evident.

When the force acts by impulsion, as in the engine beam, the velocity of the motion must be taken into consideration; for if the effect of the moving force be greater than the elasticity of the material, it would break. Now the velocity of a double-acting or rotatory engine may be taken at a

constant quantity of 3·6 feet per second; therefore the number of pounds pressure acting upon the end of the beam, multiplied by this velocity, will give the resistance necessary to be overcome.

As regards propriety of form, the vertical section or *outline* of a beam ought to be a figure including the parabolic curve; that is, two parabolas joined base to base at the centre of motion.

The following are calculations made for a beam of an 80-horse double-acting engine; but at the time they were made, the imperfections in the machinery being so much greater than at present, the same results will not be arrived at, but the error will be on what is called the safe side.

The velocity of the piston was 216 feet per minute, or 3·6 feet per second, and 200 lbs. raised through that space in that time was called a horse power. The pressure in the boiler was $2\frac{1}{2}$ lbs. on a square inch above the atmosphere. But the pressure on each square inch of piston surface was reduced by friction, imperfect vacuum, and rarefaction of the steam by the throttle-valve, in its passage from the boiler to the cylinder, to 9 lbs. per square inch; and $47\frac{5}{8}$ inches was taken as the requisite diameter of the cylinder. Again, since the beam had to overcome the total resistance of the machine, 17·5 lbs. per square inch was calculated as the force that would act upon it, minus the velocity, or $17{\cdot}5 \times 1781{\cdot}3 = 31172{\cdot}75$ lbs. $\times 3{\cdot}6 = 112221{\cdot}90$, or 50 tons, equal the force of impulsion. But it was considered that the momentum acquired during the ascending or descending stroke of the engine had to be overcome at the moment of the change of motion, and that it was equal to the friction of the entire machine multiplied into the velocity, 3·6 feet per second. This was equal to nearly 6 lbs. per square inch of piston surface; therefore the additional strength required for the beam was $1781{\cdot}3 \times 6 \times 3{\cdot}6 = 38476$ lbs., or 17·13 tons, making a total of $17{\cdot}13 + 50 = 67{\cdot}13$ tons.

The known dimensions of the beam were as follow: length from centre of gudgeon to point where piston rod acts, 12 feet; thickness of each plate, exclusive of the flanches, 2·5 inches. It remained therefore to find the necessary depth.

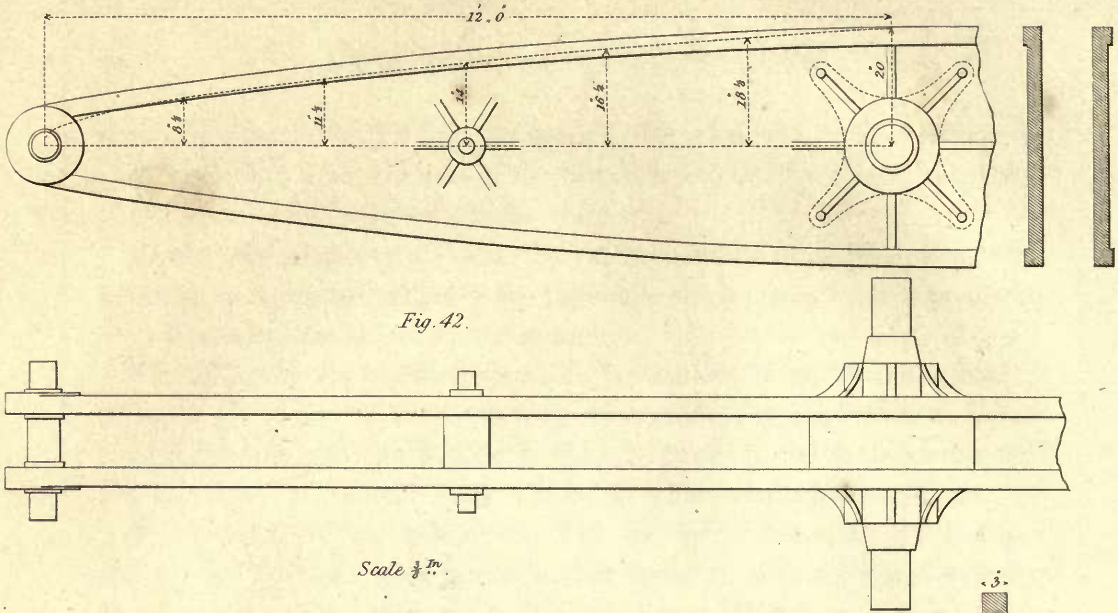
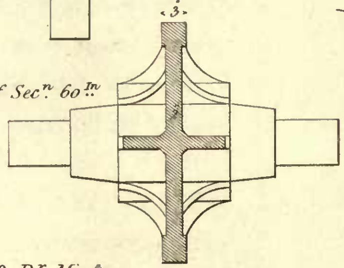


Fig. 42.

Scale ⅛ In.



Area of Secⁿ. 60 In.

45 Horse. Diamʳ. of Cylinder 36⅜ In. Stroke 6 feet. Nº 18 Pʳ Minᵉ.

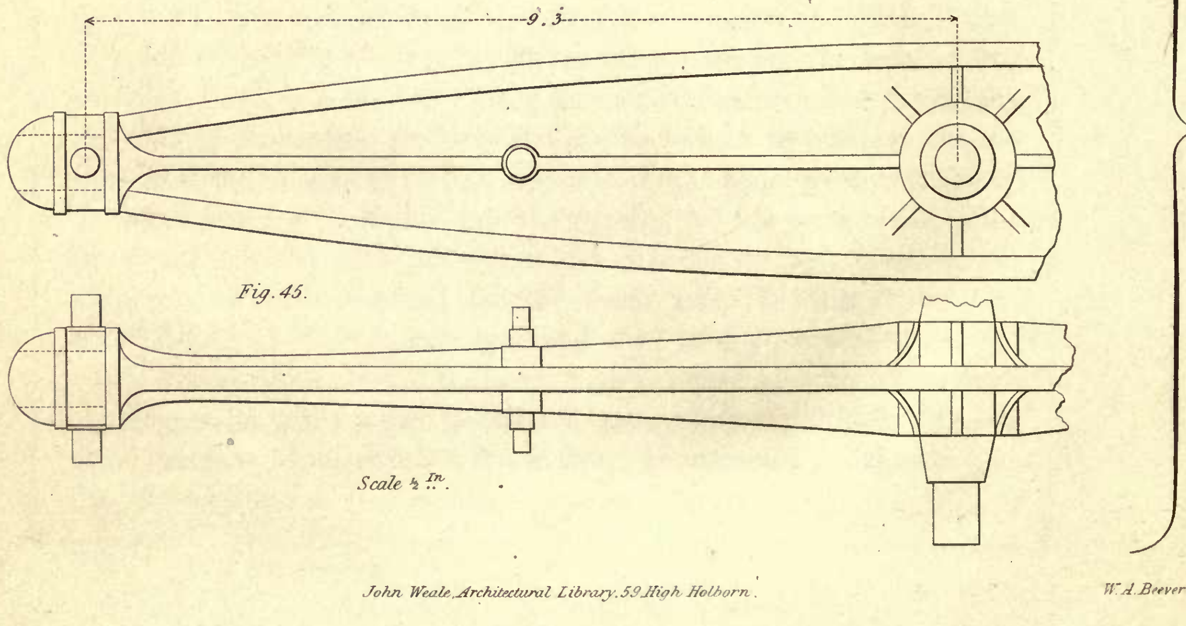


Fig. 45.

Scale ½ In.

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The datum of the computation was that a beam, supported at the ends, 1 inch broad, 12 inches in depth, and 12 feet between supports, would sustain, without permanent deflexion, the weight of 4·90[2] tons at the middle of its length. And this, in the case of a beam, would resolve itself into $\frac{12}{2} =$ length, $\frac{4{\cdot}90}{2} =$ weight; because it must be considered as if it were permanently fixed at one end, and loaded at the other; and the stress at the end by the weight is the same as the stress upon the middle of a beam of twice the length, with twice the weight laid on its middle; this beam being supported at both ends.

The thickness of experimental beam, increased to 5 inches, would bear $2{\cdot}45 \times 5 = 12{\cdot}25$ tons. The length increased to 12 feet would reduce this one half, or $\frac{12{\cdot}25}{2} = 6{\cdot}125 \because \frac{67{\cdot}13}{6{\cdot}125} = 10{\cdot}96$ and $\sqrt{10{\cdot}96} \times 12 = 39{\cdot}72$ inches, the required depth of the beam. With these dimensions it was actually erected, and has now been at constant work rather more than twenty-four years.

The elevation, plan, and cross section of this beam are represented in fig. 42, Plate VII. The lengths of the ordinates are figured, and the line of the parabola dotted. Unsatisfactory as this mode of proceeding may be to theorists, it was nevertheless that adopted by one whose knowledge of the doctrines of statics and dynamics was perfect. The success attending this example furnishes a dangerous precedent; for it is much weaker than most other beams for the same power: and although it might not actually break, if subjected to violent concussion, it would be very liable to do so.

The following are the areas of the cross sections of beams taken at the centre from three different sources: area in above example, 198·60 inches; average of seven cases from beams that have been at work three years, 240 inches; by Tredgold's rule (Practical Essay on the Strength of Cast Iron, p. 273, *et seq.*, 4th edition), 427·4 inches.

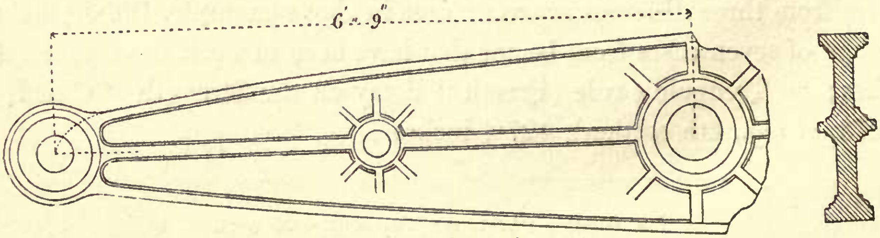
[2] Tredgold, 4·55 tons; Turnbull, 4·95 tons.

It has been remarked, that the only difficulty which presents itself in these calculations is the determination of the *quantity* of impulse given to the end of a beam. In an engine employed for spinning, pumping, blowing, or any *regular* work, the smaller areas may be used with confidence, and the total pressure that can act on the piston, plus $\frac{1}{3}$rd of this pressure, multiplied by the velocity, will give the force. But for engines used to drive bone-mills, stampers, fulling-stocks, or breaking down rollers, the dimensions can only be given by experience. Workmen are very apt to do mischief by bringing "blooms" to all the rollers at once, and what they term "stall" an engine, when either it is brought to a dead stand, or something breaks. These pages are not, however, intended for disquisitions on points of theory. The present digression is merely an attempt to convey some idea of the causes which lead to the error of making prodigiously strong beams, and to show that there is more excuse for the use of unnecessary metal in the moving, than in the stationary, features of engines.

The friction of any part, *cæteris paribus*, increases very nearly in the same proportion as the weight; therefore a beam that is exactly strong enough is advantageous in this respect, as well as being more pleasing to the eye.

In the outline of a beam, that which approaches nearest to a parabola will be the most perfect, both with regard to mechanical laws, and beauty of proportion. Within this figure it will be weak, if the centre be only of the right dimensions; and all beyond that curve will be weaker also, by

Fig. 43.



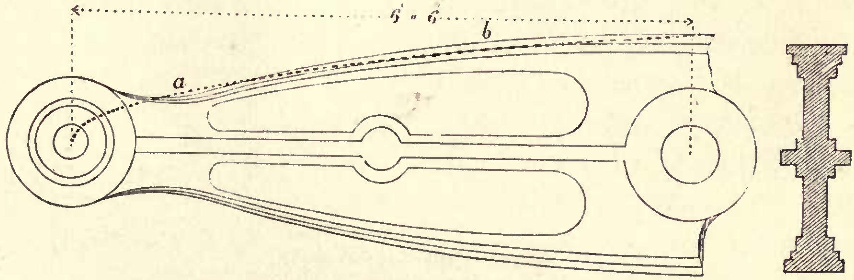
39½-inch cylinder—4 feet stroke.

the weight of such extra matter. As to propriety of form, then, for an engine beam, there cannot be two different opinions.

Fig. 43 is an example of the beam of a 50-horse rotary engine, with a velocity of 200 feet per minute. The area of its transverse section is 63·75 inches; the outline is a parabola, having its vertex at the centre of the end gudgeon.

Fig. 44 is a beam for a 45-horse engine, upon the same construction as the last. Its sectional area is 90 inches; and supposing it to be no more

Fig. 44.



39-inch cylinder—3′ 9″ stroke.

than necessary, the neck at *a* is too weak, because it falls within the line of the curve; the portion at *b* is too *strong*, because it projects beyond. These errors could not fail to strike the eye of the most casual observer, and to a man of taste and judgment would appear highly offensive. It is impossible to guess the designer's motive for making his beam in this form, since every deviation from the proper form is disadvantageous, both for beauty and strength.

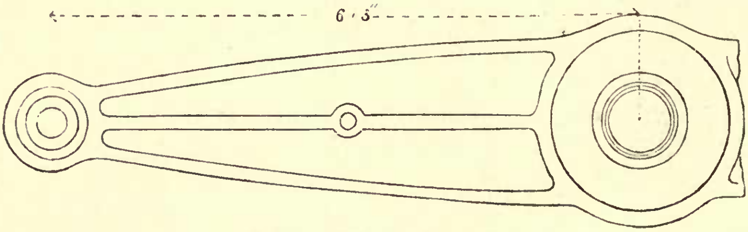
Fig. 45, Plate VII., shows a beam for a 45-horse house engine, used for rolling lead. The end gudgeon is fitted upon a turned bearing at right angles with its centre of motion. By this arrangement the contour is perhaps slightly broken; but as it is one possessing the advantage of allowing the perpendicular links play, and of self-adjustment to some extent, it may counteract the small defect above mentioned. Custom also lessens minor imperfections; for taste is generally thus influenced when

there is no axiom for its regulation, or decided law to govern it. Beams for engines of a higher power than this are made double, as in fig. 42, for the convenience of lifting or fixing them in their places.

The dimensions of cast iron beams for marine engines also vary to a great extent, and rules for the determination of their strengths are arbitrary, especially in sea-going ships, where the machinery is exposed to heavy blows from the sudden emersion of the paddle-wheels to a greater depth than that estimated.

Fig. 46 is a beam for an engine with a 42-inch cylinder, differing in

Fig. 46.

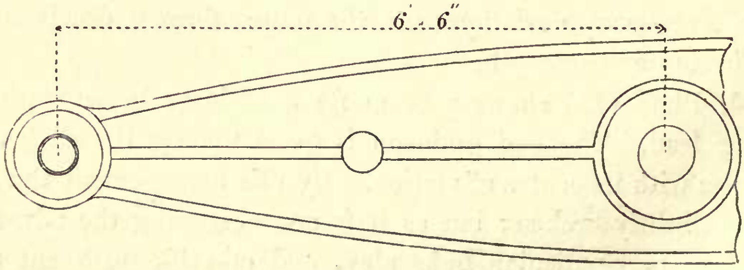


42-inch cylinder—4 feet stroke.

construction from any of the previous examples, and having the centre swelled out to allow a greater quantity of metal to be placed round the gudgeon.

Fig. 47 represents another beam for a sea-going vessel of the same

Fig. 47.

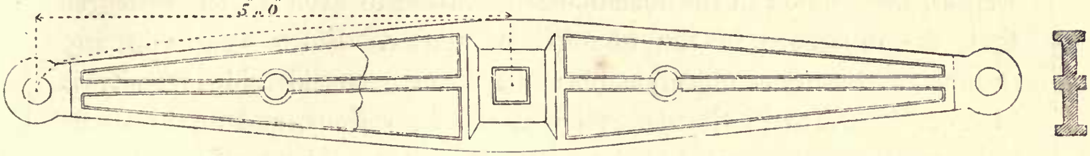


42-inch cylinder—4′ 2″ stroke.

power as the last, but with a much greater sectional area.

Fig. 48 is a valuable example, because it furnishes us with material from which much that is useful may be gained. The boat was employed

Fig. 48.

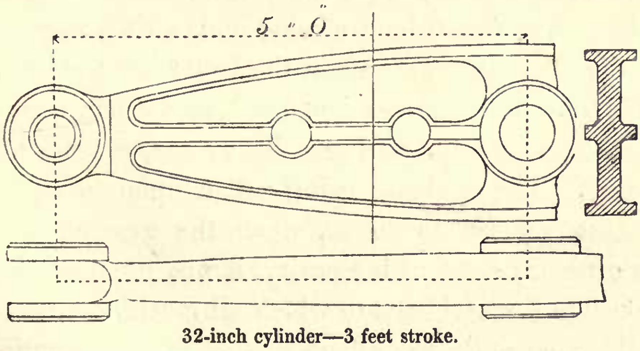


33-inch cylinder—3 feet stroke.

for river service in the first instance, and performed its duties without difficulty; but during its first voyage to sea, the unequal shocks to which the beam was exposed caused a fracture at the place marked in the drawing, having a sectional area of 27 inches. The new beams erected in the place of the old ones had precisely the same dimensions at the centre, but the arms were increased to the size shown by the dotted line, the place of the fracture having now the area of 31 inches; and this has been found ample. The design of this beam is very inferior, from the frequent occurrence of crude angles: the square centre especially is displeasing, besides being more difficult and expensive to fit.

The next illustration, fig. 49, exhibits another dimension, much at

Fig. 49.



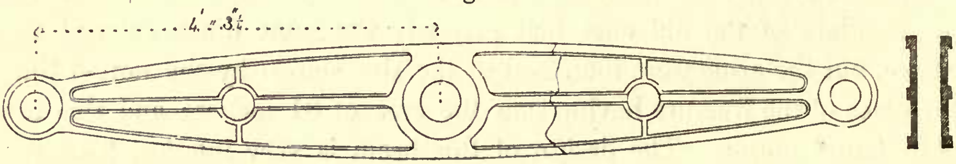
32-inch cylinder—3 feet stroke.

variance with the greater majority of these parts of marine engines. The engine is of less power than that to which the last beam was attached,

and its sectional area at the same distance from the centre of motion is 56·37 inches. Now discrepancies to a certain extent are allowable, but there is moderation in all things, and by this enormous addition of weight, the friction of the machine is increased to even a greater degree than the difference in the quantity of matter. Extra weight in any stationary feature is objectionable; but when a considerable velocity is to be conveyed to it, the defect becomes very serious, and an injurious influence is communicated to the entire structure. These two last beams are single, or rather, are not formed of parallel plates in separate castings.

Fig. 50. Amongst the numerous incidents by which experience is

Fig. 50.



31-inch cylinder—2′ 6″ stroke.

so much assisted, and which adds to the useful stock of memoranda to be met with in the note-book of the practical man, the following may be quoted. These beams, made with two plates, each 14·5 inches deep in the centre, by 1 inch thick, were fixed to an engine with a cylinder 31 inches diameter, 2 feet 6 inch stroke, and with a velocity of 155 feet per minute; the pressure of steam in the boiler being 4½ lbs. above that of the atmosphere. The engines had performed their work steadily for six months, when suddenly, during a heavy sea, a plate of one of the beams gave way. The engineer being called upon to replace the beam at his own cost, refused to do so, upon the ground, that as it had performed its ordinary duty with security, it was not just that he should become responsible for accidents to which all machinery, exposed to such risks, was liable: he moreover affirmed, that notwithstanding the above event, the same sectional area was ample for an engine of that power; nor would he increase the dimensions in any similar instance. The case

was referred to arbitration, and the remaining sound plate of the same beam was subjected to the following experiment:—it was fixed upon a turned bearing, and secured by keys; a fine line was tightly stretched to correspond with the centres of the gudgeons, and each end loaded gradually until it broke, when the weights were found to be 16 tons, 3 quarters, and 11 ℔s. on the side of the fracture, and less by 27 ℔s. on the other; which made the resistance of the four plates, when at work, equal to 67 tons, 1 quarter, and 16 ℔s., very nearly three times that given by the supposed necessary calculation.

As it could not be thought the engine had exerted this enormous force, it was presumed that the fractured plate must necessarily have had a flaw; but every particle of the metal exhibited the lustre of newly broken iron. In fact, such occurrences as these cannot be explained, and as it is utterly impossible to assign a reason why they should happen, it is equally difficult to insure perfect freedom from accident. The means employed for connecting the different moving parts with one another will generally have great influence, as far as regards their safety; since, if they are not allowed play, the bearings require to be so exactly fitted, that if one brass or gudgeon wears more than another, some deflexion must take place in that which is farthest from the point of impact; and if that deflexion is greater than the elastic power of the material, it will of course break.

Wrought iron beams appear for this reason singularly appropriate for marine engines; and it seems a contradiction to employ wrought iron cranks, and then to break the connexion by making cast iron beams.

The great diminution in the weight of matter is also an advantage which these beams possess over those of cast iron.

The expense of fitting, the complication of parts, and consequently the increase of friction experienced in *beam engines*, have led engineers to contrive means by which they may be simplified, and the beam dispensed with. The latest war steamers are fitted with engines of this kind, and

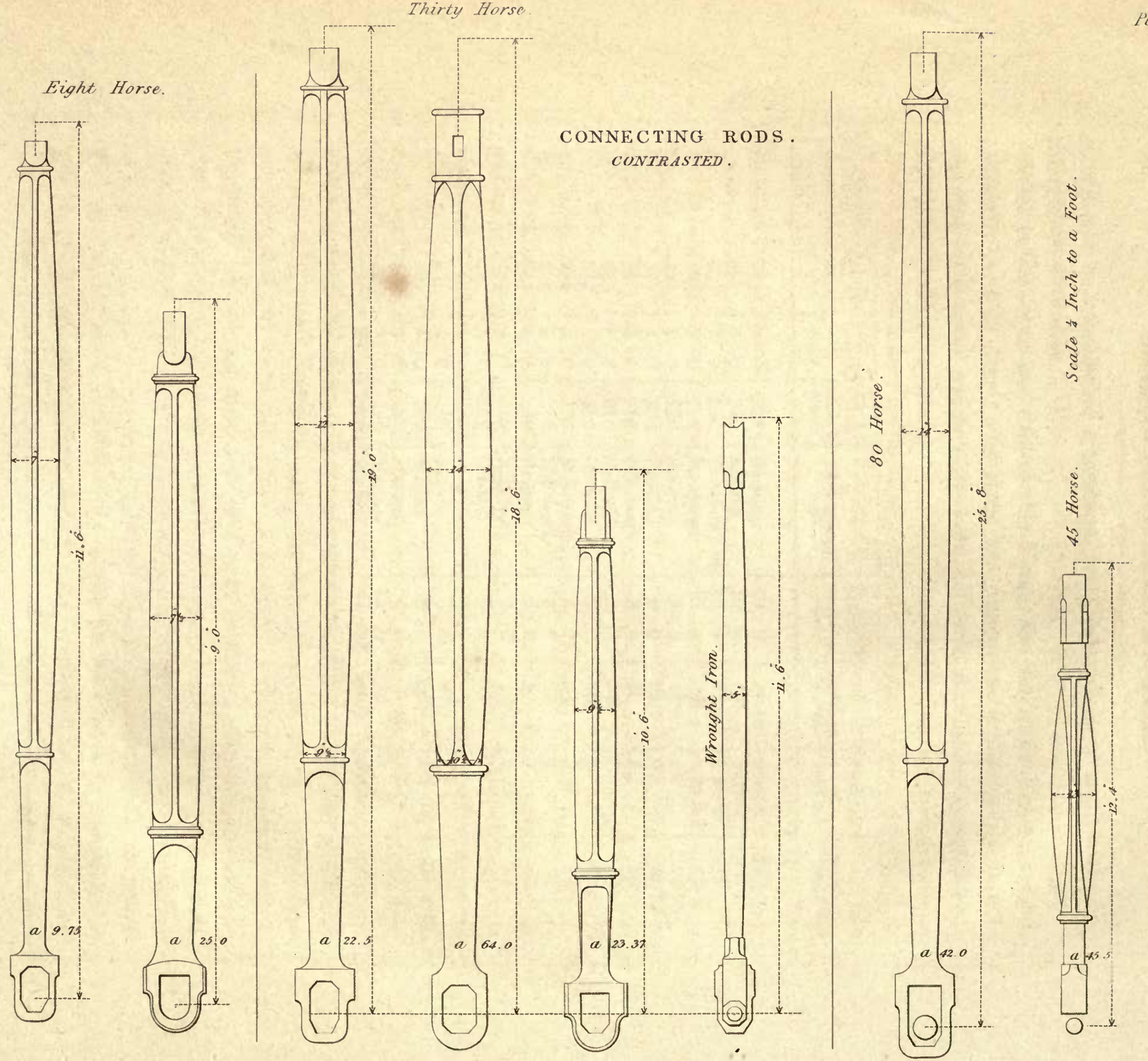
it will not be long before a beam in every description of engine will be thought an absurdity.

With reference to the title of this Essay, the following Table may be considered out of place; but since the dimensions contained in it are practical, and those which have been collected during its compilation, they may perhaps be useful.

Nominal power of engine.	Diameter of cylinder.	Length of stroke.	Velocity in feet ⅌ minute.	Description of work.	Length of beam from centre.	Depth at centre.	Thickness of metal.	Sectional area.
80-horse	$47\frac{5}{8}''$	7′ 0″	216	Blowing	12′ 0″	39″72	2·5 × 2	198·6
. .	$47\frac{7}{8}$	8 0	210	Rolling	12 4	48	2·5 × 2	240
65	$42\frac{7}{8}$	7 0	216	Grinding corn	10 9	42	2·5 × 2	210
56	$40\frac{3}{4}$	7 0	180	Pumping	10 4	36	2·25 × 2	162
55	$39\frac{1}{2}$	6 9	220	Blowing	9 6	38·5	2·5	96·25
50	$39\frac{1}{2}$	4 0	200	Blowing	6 9	25·5	2·5	63·75
45	39	3 9	210	Mill-work	6 6	30	3	90
45	$36\frac{5}{8}$	6 3	216	Rolling	9 3	30	2	60
36	$31\frac{7}{8}$	6 0	216	Blowing	9 0	30	2	60
20	$24\frac{3}{4}$	5 0	190	Mill-work	8 $2\frac{1}{2}$	24	2·25	54
20	$23\frac{7}{8}$	5 0	216	Mill-work	8 0	25	2	50
14	$20\frac{1}{4}$	4 6	200	Rolling	7 8	21	2	42
12	$18\frac{1}{2}$	4 0	216	Mill-work	6 10	22·25	2·25	50
8	15	4 0	216	Oil-mill	6 8	18	1·75	31·5
	42	4 2	180	Marine	6 6	27	2 × 4	216
	42	4 0	200	Marine	6 3	23	1·5 × 4	138
	33	3 0	180	Marine	5 0	17·25	2·25 × 2	77·6
	32	3 0	180	Marine	5 0	22	3 × 2	132
	31	2 6	200	Marine	4 $3\frac{1}{4}$	14·5	1 × 4	58

CONNECTING RODS.

CONTRASTED.



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The transmission of power through the connecting rod, the alternating thrust and pull which influences it, the constant variation in the direction of the motion, and consequently the change in the quantity of strength required at each different portion of its path, renders the calculations for its dimensions exceedingly complicated; nor are they at all satisfactory, since in no single instance has the theoretical resistance been found correct when adopted in practice. The quantity of deflexion or "swag" that affects the direction of the downwards thrust is perhaps the most essential point to be considered in the analysis, and the spring from the elastic properties of the metal, which must be sensibly felt through the rod immediately and on the instant of the change in the motion, exerts a serious power, which experience alone can correctly appreciate. And since this is felt more in long than in short rods, the dimensions will not be in the *theoretical* proportion to their respective lengths, although it has been so stated.

The examples of connecting rods given in Plate VIII. will show by mere inspection how very much their proportions differ from one another, and how seriously mistaken some have been in their ideas of necessary strength. Those for 8-horse power have a difference in their sectional area at *a* of 16·75 inches; the greater section belonging to the shorter rod, which is rendered clumsy in appearance, and is an injurious drag upon the engine. The rods for 30-horse engines also exhibit discrepancies which would not exist if the theory of their action were properly considered. As in the case of beams, the different kinds of work for which they are employed would make some difference in their requisite dimensions, but not nearly so much as the drawings show. Wrought iron is very appropriately used in instances when the rod is of inconsiderable length, since it gives an idea of even greater security, with much more elegance.

Propriety of form and an exact adjustment of material are equally essential in these features. It is perhaps impossible to convey to the

mind any just reason for the cause, or to make it sensible to the merits or demerits of a design, without mathematical demonstration, and even then well-directed judgment must be exercised in the arrangement of the parts; for a mere theoretical rod would look strangely deficient to the practised eye, and would surely be equally disadvantageous when comparison had to be made with *quantity of work performed.* The jingling contrivances for transmitting power which we constantly see exhibited, arise solely from the want of practice or of care in the artist who planned them; and the theorist would be equally lost if he should venture beyond his construction upon paper: his neutral axis, so essential to the nice solution of his equation, would be found any where but in the expected place: his *vis viva*, estimated to the uttermost fraction, would contradict him, and the *modulus of elasticity* of his material would display itself in a different light under every varying gradation of quality, from Old Park iron downwards. Notwithstanding all this, however, it is doubtless a gratifying exercise to draw from assumed data the ever-lastingly changing results which arise from mathematical investigations, and to find them lead step by step to the anticipated solution; but it would be just as unpleasant to find that the magical Q. E. D. had lost its charm when put to the test of practice, and which it assuredly would in the cases just referred to.

Propriety of form in the detail of machinery depends upon two circumstances. The first is, that the parts subject to wear and tear, and influenced by strains, should be capable of motion or adjustment: the second, that every portion should be equally strong, and present to the eye an uniform figure, or one that is consistent with its degree of action: theory, practice, and taste, all must combine to produce such an one. A great extent of beauty is attainable in all the details, but mathematical reasons cannot be given why a certain arrangement of lines should be preferable to another, provided they are equally strong. Truth does not strike us without the assistance of custom; but so great is the force of custom, that unassisted by truth it has worked the greatest miracles; and

it certainly must be this universal Mentor which gives us the power to choose between forms. It has been already frequently observed in speaking of general contour, that sharp angles and irregular curves disturb the eye: these must be also considered in detail. Owing to the above circumstance, (the absence of a decided law,) opinions alone can be given upon the various parts of machinery which follow: it is not possible to do this without disagreement, but it will produce at least one good effect, if no other; it will suggest thought, so often absent in these designs.

Figs. 51 and 52 represent two different methods of forming the crank ends of cast iron connecting rods for land engines. Concerning the first there cannot be a dissent: it combines nearly all the essential properties for strength and beauty; it is capable of high "finish," without being rendered "meanly showy;" and the expense of planing the flat face would be trifling. The swell on each side is to allow a broad bearing for the key, and therefore has a meaning.

The second figure is in the opposite extreme: it is heavy, devoid of symmetry, and distinct

Fig. 51.

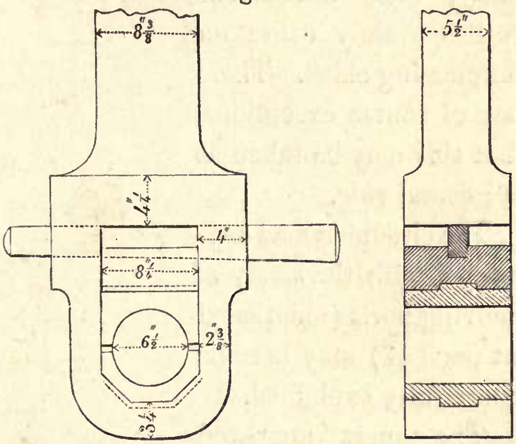
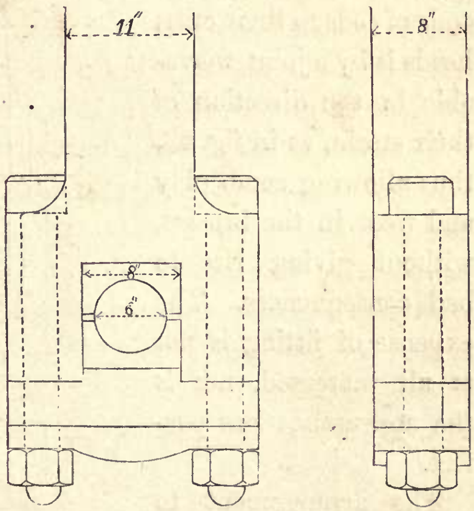


Fig. 52.



Connecting rod ends—80-horse land engines.—Cast iron—scale $\frac{3}{4}$ inch.—Length between centres 25 feet.

means are employed for resistance, by which the determination of the strength is rendered uncertain, and the liability to error increased.

To gain any end, no means can be too simple, and, if possible, the same material should be used throughout; for if wrought and cast iron, for instance, be brought in close contact, performing the same extent of duty, their dimensions will certainly cause an unpleasing effect. There are of course exceptions, but this may be taken as a general rule.

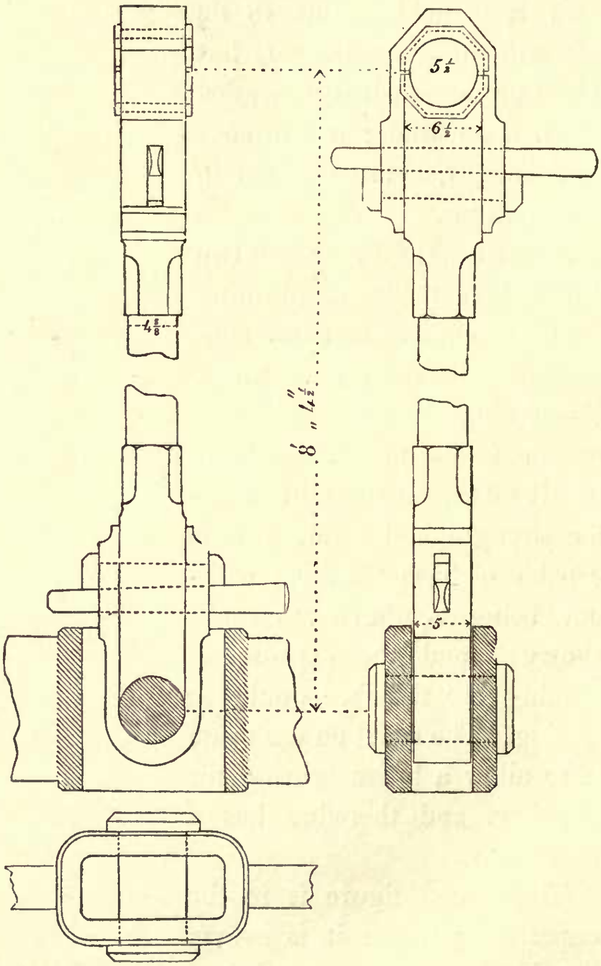
The circumstances connected with the safety of moving parts (mentioned at page 47) may here be more fully explained.

The most approved system of attaching the ends of rods to their cross heads is by a joint, moveable in the direction of their strain, as in fig. 53, thus allowing some play and wear in the brasses, without giving rise to bad consequences. The expense of fitting is not at all increased, nor is the appearance less perfect.

The arrangement to be avoided is represented

Fig. 53.

Crank end.

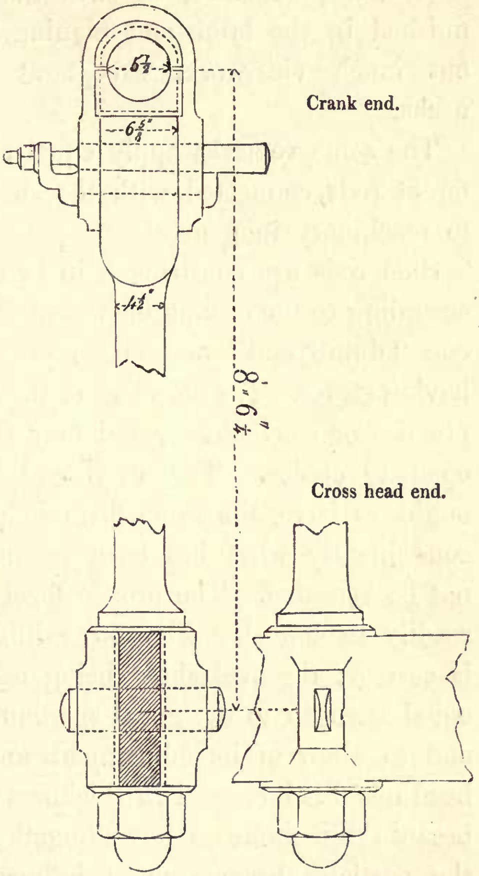


Connecting rod ends—80-horse marine engine, wrought iron.—Scale ¾ in.

in fig. 54, and it must be obvious, that unless every bearing be exactly true and square, the strain will be unequally distributed; and if the quantity of error be greater than the elastic power of the material, a permanent deflexion will be established, which may be considered as the first stage of fracture.

The form of ends made with a strap and cotter does not admit of much variation: those shown in the annexed diagrams are the most approved. The octagonal neck below the square head should always be introduced; it is a graduation towards the round part of the rod, and gives a character to the work. The shaft of the rod should swell out from $4\frac{3}{8}$ inches at the neck to $5\frac{1}{2}$ inches at the middle; and mouldings at this point should be studiously avoided, since it is decidedly "constructing an ornament" when it can be of no use whatever: it also breaks the line, and prevents the eye from following it.

Fig. 54.



Connecting rod ends—80-horse marine engine, wrought iron.—Scale $\frac{3}{4}$ in.

It may also be mentioned here, that the pins and gudgeons about which there is any constant motion should be larger in diameter than is actually required for strength; for the rubbing produces heat, slight expansion consequently follows, and thus the friction of a small pin is found in practice to be greater than that of one moderately larger in diameter.

The description of work put upon wrought iron rods should be plain and square, perfectly free from any unnecessary projection, and their shapes should, if practicable, be such that they may be finished in the lathe and planing machine without much vice-work, except at the octagonal necks.

The same remarks apply equally to all the different rods connected with the steam engine and to machinery in general.

Side rods are constructed in two different ways, according to the custom of the engineer, either with one "dumb end" and strap, or with both ends having straps. The selection of these is a matter of practice or convenience, and may therefore be left open to choice. The strap end has, or rather ought to have, the same form in every instance; consequently what has been previously said will not be repeated. The proper form for the eye is readily explained. Fig. 55 exhibits that which is correct; the oval shape being necessary to give equal strength to the metal surrounding the brass, and to allow of its adjustment and wear. The head metal is increased in thickness from the sides, because the strain is not altogether tensile, and the particles become more influenced by *stress*, requiring a greater area for equal resistance. The external figure is often varied, as in fig. 56, but not with good effect, as far as figure itself is concerned.

The circular eye, fig. 57, is not calculated for equal strength, nor is the brass bush practically

Fig. 55.

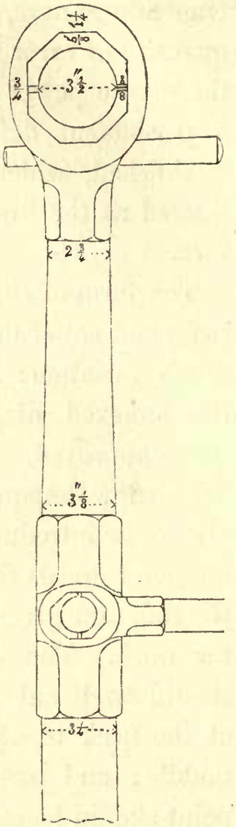
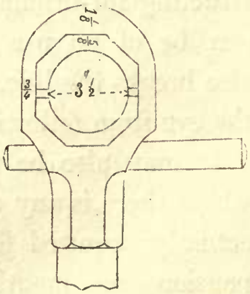
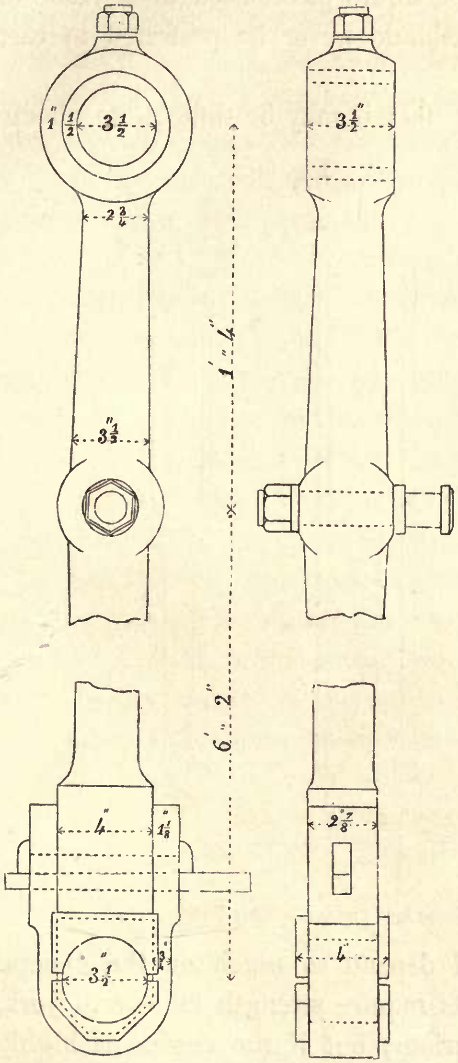


Fig. 56.



Side rod—50-horse marine engine.—Scale $1\frac{1}{2}$ in.

Fig. 57.

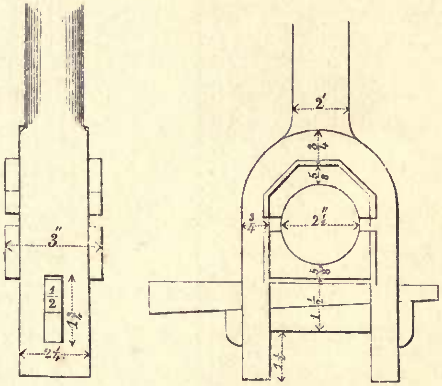


Side rod—50-horse marine engine.—Scale $1\frac{1}{2}$ in.

correct; for there is no provision for wear, and the pin that holds it presents an unpleasant excrescence.

Fig. 58 is a sketch from the air-pump side rod of a 50-horse marine engine. In actual construction

Fig. 58.



there is not a *material* objection to the use of such a form when hidden from the sight, as this would be; but it would be better to avoid the frequent use of this figure, since it does not present, in common with the other ends, an equal idea of security and finish.

While upon the subject, the eyes and arrangements of perpendicular links, &c., may be considered. Fig. 59 shows a perpendicular link from an 80-horse land engine. The fitting-in piece between the brasses is somewhat old-fashioned, and unnecessarily strong, but simple, and to the purpose; indeed, it is far superior to

many we see at the present day. These dumb pieces used to be made of oak or mahogany; but this material should never be preferred to cast iron.

Another form is represented in fig. 60: it may be difficult to choose

Fig. 59.

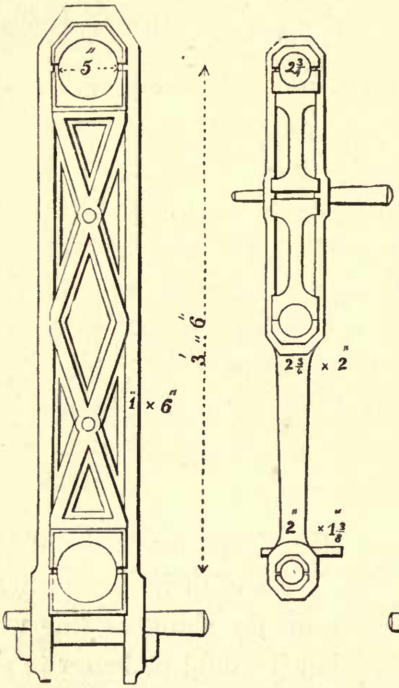
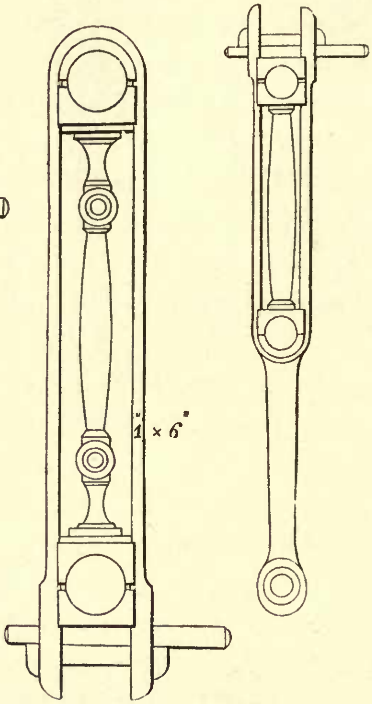


Fig. 60.



Perpendicular and back links—80-horse land engines.—Scale ¾ inch.

between these, as the propriety will depend so much on the general character of the engine. If the parts require strength for severe work, the first is perhaps the most appropriate; but if the engine is highly finished, the latter would be usually preferred. This circumstance must always have weight in the designs of detail: it would be absurd to place a light and highly finished portion in juxtaposition with a mass of black metal, where the recommendation was merely weight and stability. It would be equally wrong to introduce an unfinished and crude piece of

detail amongst those possessing elegant contour and workmanship. A little thought on the duties which each separate part has to perform is all that is necessary to the production of correct design. The figures adjoining are the "back links" of the same parallel motion, and to which the previous observations have also reference.

Drag and connecting links, from the different methods of forming them, present subjects for comment, and it is only by gleaning from the works of engineers that diversity of shape can be imagined. So simple a part it would be thought could only be bungled by great want of attention, and yet that represented in fig. 61 is from the hand of a justly esteemed maker. For such a construction it is light, but for a drag link it is heavy and inappropriate. The most efficient means that can be adopted for this purpose is explained by figures 62 and 63; and this arrangement may be used in every position where a connexion has to be effected, either between two pins, or between a cast iron rod and its

Fig. 61.

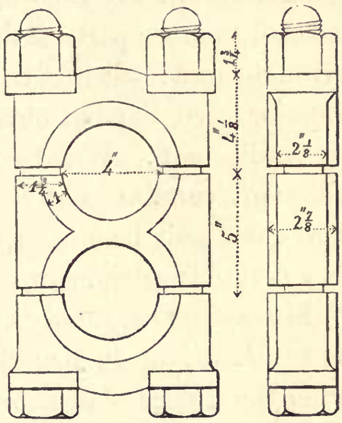


Fig. 62.

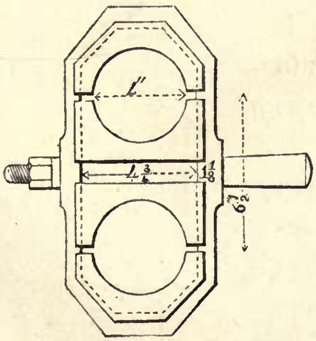
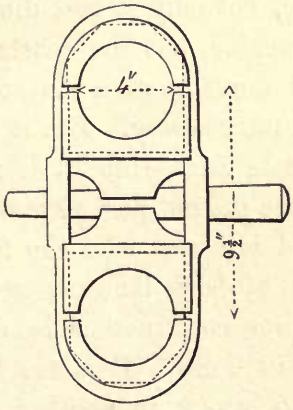


Fig. 63.



Drag links—50-horse marine engines.—Scale 1½ in.

gudgeon. They are of course made of wrought iron, being the material best suited to the description of force which goes through them. The finish at their heads may be either square or circular, according to the taste of the engineer, or the general character of the machine. The strain will certainly go through the $1\frac{3}{4}$-bolts in fig. 61; but the remaining parts being of cast metal, the link becomes necessarily clumsy.

The next class of detail that may be noticed as presenting scope for good taste are the caps for rods, from whence power has to be communicated to other parts of the machine. These are made both in cast and wrought iron: when of the first material, they must look heavy from its inferior strength; but notwithstanding this fact, they are by far the most generally used. Why?—is a question that would be found difficult of solution; certainly not because they are cheaper, since the variation in cost could only be a few shillings, an insignificant difference where beauty is a desirable attainment.

Money is so earnestly coveted by some, that every other consideration is swallowed up in that single thought; propriety of form, security, and even the science of their profession, is neglected in the study of how to get the most. With these no argument can have force; no reason, however just, can convince them that by due attention to the *first principles*, not only is cost diminished in a single machine, but the constant alteration which is sequent on a slovenly design is rendered unnecessary. But it is needless to repeat these facts, since it is not for those persons the present pages are written.

Fig. 64.

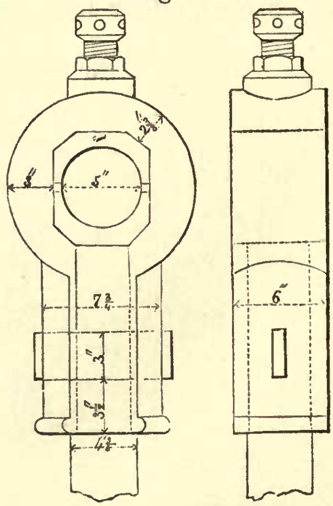
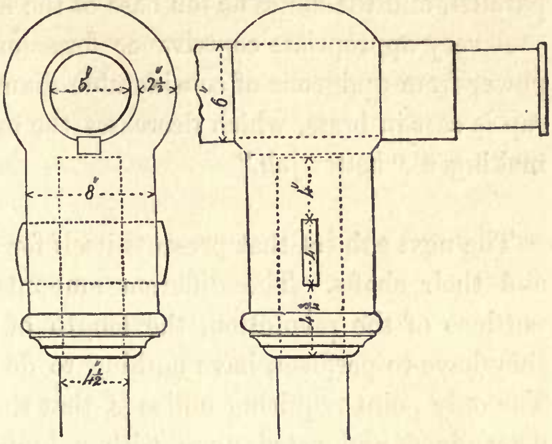


Fig. 64 is a cast iron cap for the piston rod of an 80-horse land engine. The *principle* of its construction is erroneous, as well as its form. It is too light in one place, too strong in another, and has an

appearance of neglect quite unpardonable.

Fig. 65.



The cap represented by fig. 65 is likewise of cast iron, and for that metal exhibits judicious proportions; the mouldings at the bottom, however, should be dispensed with, for they are not essential, and look frivolous. These things ought not to be treated like the appendages to a fire-grate or a household utensil, but should possess a simple and severe outline, with nothing either superfluous or *merely* ornamental. Besides, the step that is unavoidable between the diameters of the two adjacent parts should be decreased, rather than be made more conspicuous by an attractive object.

Fig. 66 is a wrought iron cap for the same purpose, and from an engine of the same power. It is not handsome, but it is light and

Fig. 66.

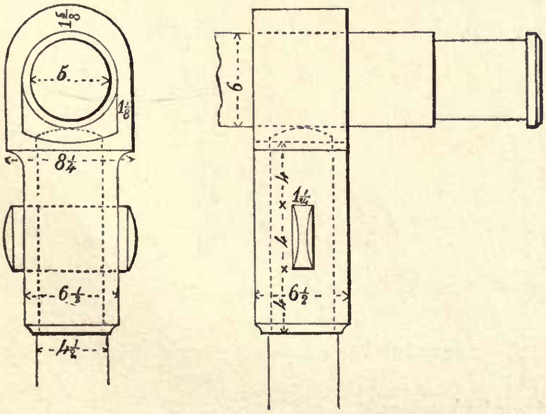
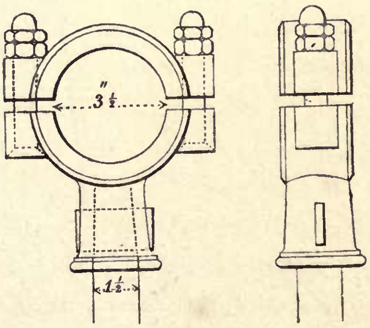


Fig. 67.



simple: it might be improved by the lines of the curves being kept more parallel, and the angle at the base of the head being omitted.

A very appropriate contrivance for communicating a small amount of power from gudgeons of considerable diameter is shown in fig. 67. The cap is cast in brass, which decreases the expense of workmanship, besides making a "better job."

The next subject that presents itself for consideration consists of cranks and their shafts. The different amounts of tortion felt at the several portions of the revolution, the length of the "journals," and the work they have to perform, have nothing to do with the present investigation. The only point requiring notice is, that the area of one crank shaft being determined and acted upon with a known leverage, all others can be determined by the rule of proportion; the areas depending directly on the quantity of power and the length of the crank. Attention to this simple rule enables us to retain the proportions of a crank; for the shorter it is, the less will be the diameter of its shaft. The area of a shaft with a

Fig. 68.

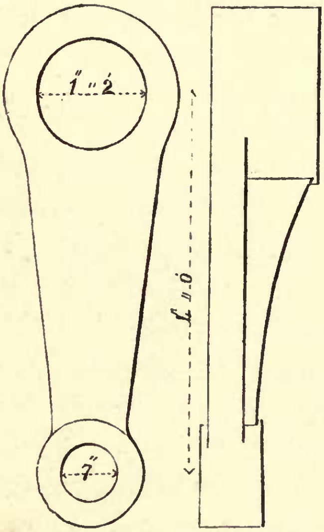
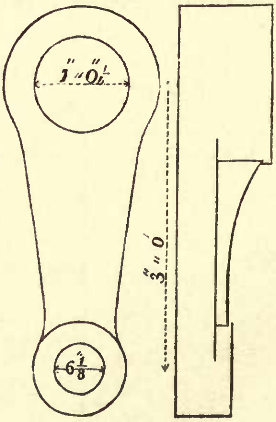


Fig. 69.



80-horse land engines.

leverage of 4 feet being 153·9, that with a leverage of 3 feet will be 115·4, which will be observed by reference to figs. 68 and 69. The first is very correct in its form: the diameter of the shaft is $\frac{1}{3}$rd greater than is found by calculation, which appears essential to allow for wear and sudden impulsion; the sides are straight lines joined into the circles by gradual curves, and all the faces are perfectly square. The area of the section at the greatest width is equal to the area of the shaft, minus the difference of leverage; that of the neck is one-half. The breadth of bearing upon the journal is 14 inches, which is ample for a crank of this size; and many of our leading authorities consider the breadth to be always sufficient, when made the same as the diameter of the shaft, for engines of any power whatever. Fig. 69 is from an engine of the same power as the last, but with 2 feet less stroke. The crank is precisely similar in its construction.

Fig. 70 is a crank for a 45-horse land engine. The correct diameter of the shaft is 9 inches; but in this example it being made 11$\frac{1}{2}$, the figure

Fig. 70.

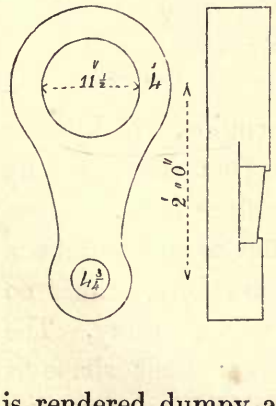


Fig. 71.

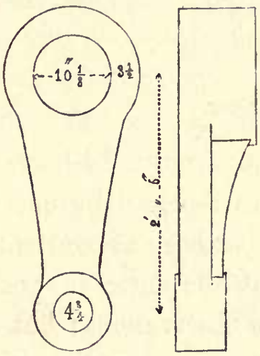
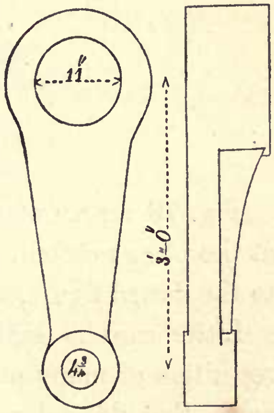


Fig. 72.

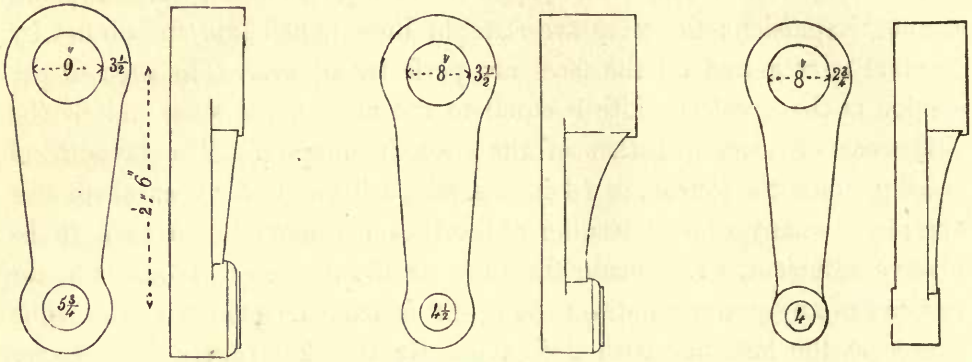


45-horse land engines.

is rendered dumpy and unmechanical. The others, figs. 71 and 72, are appropriate. The remaining sketches of cranks show the errors that have

crept into the calculations of engineers to a still greater extent. Figs. 73, 74, and 75 are of proper dimensions; the others are faulty.

Fig. 73.



20-horse land engines.

Fig. 74.

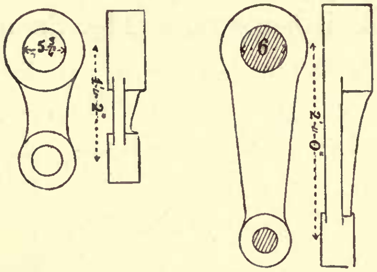


Fig. 75.

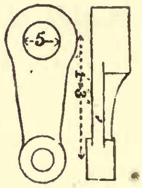
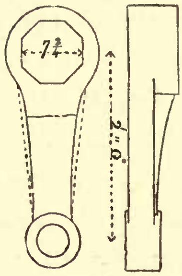


Fig. 76.



10-horse. 14-horse.

Fig. 76 represents a crank from a 14-horse land engine, which broke at the place marked. It was replaced by one having the sides lined up to the dotted figure, which has been at constant work since 1825.

Little can be said about the form of cranks that would not be a repetition of many previous observations; but there are few, perhaps no parts, that depend more upon proper dimension for their beauty. The same remarks hold good with wrought iron cranks: their shape is necessarily different, owing to the difficulty, if not impossibility, of forging them with back ribs. The main limb is therefore a simple straight lever,

which should be kept square at the external angles, and planed bright upon the face.

The principal features and details of the steam engine, as separate members, have now been discussed. A few words may be said concerning their positions, having reference to their duties performed when brought into a system.

Uniform direction, compactness, and simplicity are the three necessary principles to which the strictest attention must be paid before a perfect engine can be designed. The directions of members ought to be straight lines, running as nearly parallel to each other as the nature of their movements will permit. They must go directly to their object, so that their distinct use is not hidden. Cranked or bent levers, made so to avoid other parts, are unsightly and vulgar, giving the appearance of unexpected additions, of which a man possessing true taste would never be guilty. Pipes should have no bends but which are at once seen to be needed, and they should be at right angles to each other on each side of the bend, not slope *generally* between two points, unless in rare cases, when the variation will not admit of a quadrant bend; but there is seldom such a contingency that cannot be avoided by attention.

Compactness consists in avoiding all unnecessary space, or placing any part at a distance from the main body, except such part be a distinct machine, or worked to serve some purpose unconnected with the engine. Collateral members should be fixed quite away, and with a decided space intervening between them and the main body; they then become separate machines, depending on their own form and proportion. It is, however, quite as wrong to crowd parts together as to make them straggle. Indeed, the exercise of the nicest judgment is required in their arrangement.

Simplicity is by far the most pleasing quality that any machine can possess. The merit which a perfect engine possesses can require no superfluous decoration; the ornaments of construction are sufficient for

beauty when designed with good taste; and proper regard to the two first principles, viz., uniform direction and compactness, are the surest means by which simplicity is to be attained.

To those who aim at every reduction of cost in the formation of an engine, attention to the rules of taste cannot fail to contribute to their system of economy, since each feature will possess the requisite form. The weight of metal will almost always be reduced; in many instances workmanship will also be less necessary; and *alterations* (tiresome and unsatisfactory at all times) will never be found requisite. Upon these grounds it is asserted that expenditure is reduced by a careful investigation of those rules which guide the propriety of form and dimension.

To those more enlightened men whose science leads them to work more with a view to improve the machine, and raise their name amongst philosophers, rather than amongst money dealers,—to those it is quite unnecessary to enlarge upon the benefits arising from the study of these laws: it will only be required to point out the true means by which the end can be gained; and some of these, it is hoped, will be found in foregoing pages.

If the power of the Author had been equal to his will, no one point would have been omitted, no argument neglected, that could in any way have served to show his views upon the subject of proportion and taste. The love of analytical inquiry into such matters goes far to render a man capable of giving opinions and laying down rules: but there are other requisites to make his opinions and rules valuable which are beyond the reach of every one, and the chief of these are opportunity and experience; the last following as a consequent upon the first, when thrown in the way of those who strive for excellence.

THE END.